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# Economic value of environmental and weather information for agricultural decisions – A case study for Oklahoma Mesonet

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ABSTRACT

For the past 24 years, weather information and monitoring provided by the Oklahoma Mesonet (the state's largest weather and environmental monitoring network) has been used by many farmers across the state to optimize their farm operations and improve profitability of agricultural production.

Several research studies delineated advantages of Mesonet weather information for efficient agricultural decision-making. However, these studies are mainly qualitative or conceptual, while comprehensive quantitative research in this field is still missing. This paper aims at filling this gap by quantifying the value of weather information for Oklahoma farmers in all climate regions, based on profitability analysis, USDA NASS and agricultural output statistics, as well as crop budgets from the Oklahoma Extension Center.

The results show that the cumulative economic benefits for agricultural production in Oklahoma from utilizing Mesonet information (assuming the profitability factor of 3.7% and with 73% of farmers applying Mesonet) amounted to $183.1 million in 2006–2014 (combining generated profits and prevented losses in agricultural production). Mesonet information was found to provide higher annual economic benefits in terms of prevented losses than additional production profits, especially in drought years. A regional analysis for Oklahoma climate regions revealed the highest cumulative benefits of Mesonet applications in the Southwest ($45.9 million), North Central region ($38.2 million), and in Panhandle ($34.5 million) in 2006–2014. Also, high temporal variations were found for all Oklahoma climate regions.

This research is focused on the agricultural sector, while it also sets the baseline for a more holistic understanding of the economic value and benefits of weather information provided by the Oklahoma Mesonet that can further be applied to other sectors in the state.

## 1. Introduction – Oklahoma agriculture and Mesonet weather tools for the agricultural sector

As of 2015, Oklahoma ranked number 1 at the national scale in rye production with 1.9 million bushels (bu), number 2 in canola production with 131.1 million pounds (lb), and number 2 with 1.95 million head of cows (ODAFF, 2015). Ten other Oklahoma grown crops ranked in the top 10 products in national agricultural statistics: hay, wheat, pecans, sorghum for grain and silage, peanuts, sunflower, cotton, and cottonseed. The area of planted cropland in Oklahoma averaged 10.2 million acres in 2004–2014, except for 2011, when agricultural production was partially compromised due to exceptional record drought leading to a sharp decline of planted areas down to 9.5 million acres (ODAFF, 2014). The net value added to the economy from agricultural production was $3.8 billion in 2015, while the total net farm income amounted to $2.8 billion (ODAFF, 2015).

Due to geographical location in the south-central part of the US, Oklahoma's agriculture has been affected by extreme climate gradients, with high precipitation levels in the east (the average annual precipitation: > = 40 in.), average precipitation in the central parts of the state (28–40 in.), and low rainfall levels in the west (= < 28 in.). Oklahoma has also been exposed to other severe weather events, like droughts, floods, tornados, which have determined production of different agricultural crops and impacted farming operations, agricultural output, and farmers' income. Due to this regional weather variability, Oklahoma has been divided into nine climate regions (Fig. 1) to better track, monitor, and predict weather changes, as well as their potential impacts on different sectors, including agriculture. Accordingly, weather conditions support cultivation of most Oklahoma native crops. Wheat production is prevailing in the western parts of Oklahoma (regions, 1, 2, 4, 5, and 7), while corn production is scattered around the state in regions 2, 4, 5, 6, 7, 9. Soybean production is mainly concentrated in the northern and central parts of Oklahoma (regions 2, 3, 5, 6). Hay production is spread throughout the state and present in each

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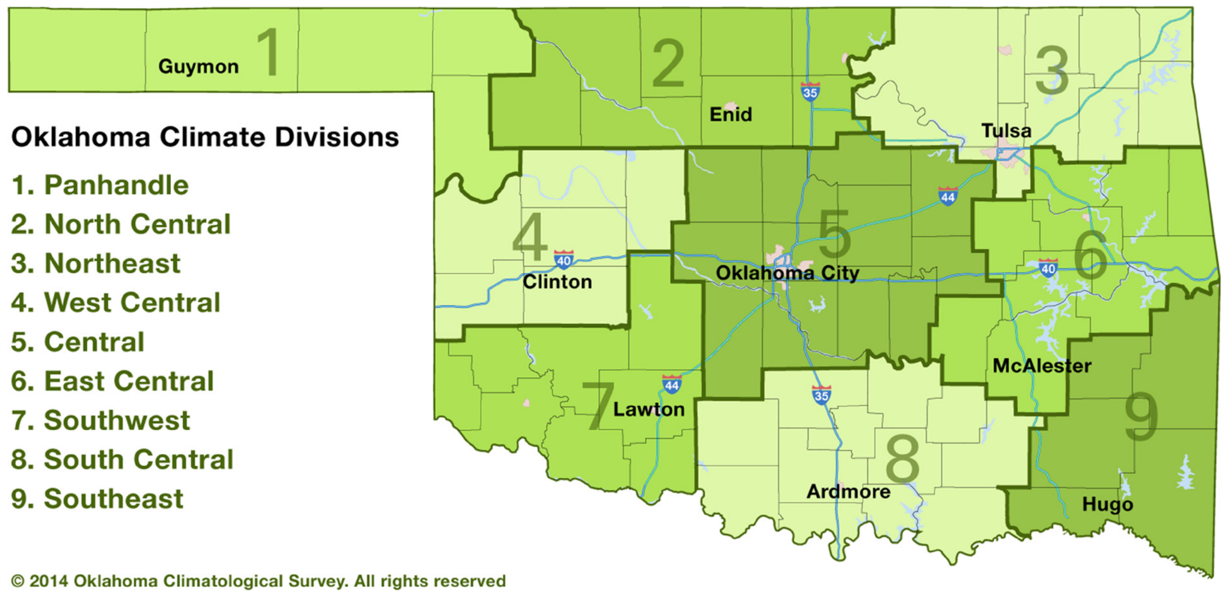


**Fig. 1.** Oklahoma climate regions.
Source: OCS (2014).

climate region.

Due to varying and uncertain weather conditions, agricultural production is highly dependent on and consistently in need of timely, updated, and accurate weather information to improve production outputs and/or prevent potential weather-related losses. The Oklahoma Mesonet was established in 1994 to serve this purpose, among others, as a joint collaboration of University of Oklahoma and Oklahoma State University, and largely sponsored by state funds.

The Oklahoma Mesonet is a network of currently 121 stations in all 77 counties in Oklahoma measuring temperature, rainfall, wind speed, solar radiation, pressure, and relative humidity at 5-minute intervals. The Mesonet measures soil temperature at various depths at 15-minute intervals and soil moisture at various depths every 30 min. It is considered the "gold standard" for weather monitoring (McPherson et al., 2007), and since its launch it has generated many socio-economic and environmental benefits for various groups and sectors (Ziolkowska et al., 2017). Specifically for the agricultural sector, the Oklahoma Mesonet has developed a variety of information tools and products to be used by farmers online or via a mobile app to help improve their planting, growing, and harvesting decisions, and/or prevent potential weather-related losses (Table 1).

As Mesonet information is free to any user with Internet access, it is difficult (or almost impossible) to determine the number of farmers applying Mesonet information or the frequency of use for everyday farming operations. In addition, it needs to be emphasized that Mesonet weather and monitoring information is commonly used by all weather broadcasting stations and news outlets in the state. Thus, farmers might not be aware of benefiting from Mesonet information indirectly.

Accurate weather information can generate significant economic benefits in regard to optimizing agricultural land use and generating additional net returns (profits) that might have been forgone if this information was not available. This has been validated by several studies that used Mesonet data to document impacts of weather events on agricultural production/variables (Illston et al., 2004; Haugland and Crawford, 2005; Lee et al., 2013). Moreover, Mesonet weather information has also been applied to prevent potential losses as a result of severe weather conditions by taking preventive and proactive measures in crop and animal production.

Even though economic benefits have been frequently reported by farmers as a result of using Mesonet weather information, studies are missing that would quantify the value of this information in the first place. As Mesonet information and tools/services are free to any user, there is neither a market value nor price nor an assumptive estimate about economic benefits that this weather information generates for farmers. Answering this question is important for two reasons. First, for years environmental economists have been discussing the issue of externalities. An externality (positive or negative) occurs when welfare (utility) of one person is affected by activities of another person without being reflected in market prices. Clearly, weather information provided by the Oklahoma Mesonet and the benefits generated by this information present an example of a positive externality for the society. Accounting for this externality can help with a better understanding of benefits to the state economy and different groups (here: farmers across Oklahoma). Second, agriculture is an important economic sector in the state economy. By contributing to the Gross Domestic Product, it impacts social welfare, which emphasizes the relevance of accounting for and quantifying agricultural production that can be attributed to provision of Oklahoma Mesonet weather information.

This paper presents a first attempt to address these issues by determining the economic value of Mesonet weather information for agricultural production in the state of Oklahoma and for each single climate region in the time span 2006–2014. Based on production net returns this holistic evaluation helped express the value of Oklahoma Mesonet weather information in monetary units.

## 2. Value of information – measurements and evaluation approaches

Accounting for and measuring economic value of information of any kind and in any discipline is a very challenging task. The main reason for this difficulty arises from the fact that information, even though one of the most powerful production factors, is generally intangible, and thus difficult to express in measurable/quantitative (e.g., monetary) units. Therefore, accounting for the value of information needs to occur in an indirect way, based on other tangible (measurable) variables. For instance, even though *information* has no market as such, *information services* have been marketed and assigned a value. Furthermore, in regard to the Oklahoma Mesonet example and the agricultural sector addressed in this paper, even though there is no market price attached to Mesonet information (Mesonet's goal is to provide free public service for the state-wide community), there is a measureable output of agricultural production that can be quantified directly. At the same time,

**Table 1**
Oklahoma Mesonet tools for agricultural producers.
Source: The Oklahoma Mesonet (2016).

| Tool | Description |
|---|---|
| Alfalfa Weevil Advisor | Insect pest tool helps farmers determine the best time to scout fields for weevil larvae based on degree-day heat unit accumulations. |
| Cattle Comfort Advisor | A year-round model of heat and cold stress levels for cattle based on the Comprehensive Climate Index by Mader et al. (2010) |
| Degree-day Heat Unit Calculator | Crop degree-day heat unit calculator for a variety of agronomic crops. |
| Drift Risk Advisor | A weather-based forecast planning tool that indicates windows of lower drift risk for spray applications. |
| Evapotranspiration and Irrigation Planner | Daily potential ASCE (American Society of Civil Engineers) Reference Evapotranspiration and potential evapotranspiration for individual agronomic and horticultural crops. |
| Farm Monitor | Displays latest Mesonet data, National Weather Service forecast, and Mesonet agricultural decision-support products for a specific Mesonet site. |
| Fractional Water Index | Point soil moisture measurement at four depths: 5 cm, 10 cm, 25 cm, and 60 cm (2 inches, 4 inches, 10 inches, and 24 inches) independent of soil type. |
| Weather Fronts | The boundary between cold and warm air masses that is monitored to anticipate air temperature changes. |
| Grape Black Rot Advisor | Grape plant disease advisor that indicates best time for applying a fungicide to minimize the number of applications and maintain good disease control. |
| Inversion | Occurs when the 1.5 meter (5 feet) air temperature is below the 9 meter (30 feet) air temperature. Inversions typically hold fog, smoke, spray particles, or odors close to the ground. |
| Long-Term Averages | Interactive graph and map making tools for comparing daily or monthly weather data to 15-year long-term averages of measured and calculated Mesonet weather variables. |
| Fire Danger Model | Estimates risk of fire ignition, rate of spread, energy release, and flame height by estimating live and dead fuel moisture based on past, current, and forecast weather conditions. |
| Fire Prescription Planner | Forecast tool to identify windows when prescribed fires can be conducted effectively and safely. |
| Peanut Leaf Spot Advisor | Peanut plant disease advisor that indicates best time for applying a fungicide to minimize the number of applications and maintain good disease control. |
| Pecan Scab Advisor | Pecan plant disease advisor that indicates best time for applying a fungicide to minimize the number of applications and maintain good disease control. |
| Plant Available Water | Estimates inches of water in a soil column from the soil surface down to 10 cm (4 inches), 41 cm (16 inches), and 81 cm (32 inches) based on soil properties at individual Mesonet sites. |
| Rainfall | Monitors rainfall amounts at each Mesonet site down to a 0.01 of an inch and provides rainfall accumulation maps. |
| Soil Temperatures | Used to minimize replanting risk for newly seeded or transplanted crops to cold or hot soils. |
| Wet Bulb Globe Temperature | Model that estimates the combined human heat stress risk of temperature, humidity, wind speed, and solar radiation. |
| Wheat First Hollow Stem Advisor | Estimates probability when hard red winter wheat has reached first hollow stem stage, wheat growth stage for terminating cattle grazing to avoid reduced grain yield. |
| Wheat Growth Day Counter | Count of the number of days with positive degree-day heat units for hard red winter wheat to tailor nitrogen fertilizer recommendations. |

unlike other marketable goods, information increases in value with an increasing use, thus exhibiting increasing returns to use. Some authors claim that information has no real value on its own; rather it only becomes valuable, when there is a demand for it (Moody and Walsh, 1999).

Methodological evaluation approaches for assessing value of information can be classified as follows (Moody and Walsh, 1999):

1 Mathematical measures of information used in communications theory (Shannon and Weaver, 1949) that are focused on the amount of information transmitted, while they ignore content or meaning (Glazer, 1991, 1993), and
2 Accounting valuation models defining information as an asset in marketing terms, such as:
   a) Cost (and historical cost) evaluation based on the original value paid to acquire the asset (purchasing price or development cost) (Henderson and Peirson, 1998; Ijiri, 1971),
   b) Market (current cash equivalent) approach based on the value information users would be willing to pay based on stated-preference methods (Chambers, 1966; McKeown, 1971; McDonald, 1968; Sterling and Radosevich, 1969), and
   c) Utility (present value) approach based on the present value of expected future economic benefits as an outcome of the information application (Godfrey et al., 1997).

The selection and application of an appropriate evaluation method to assess the value of information will depend on many factors, among others, the relevance of information to different groups (information users, decision makers, advisors). Clearly, any evaluation involving human assessments/judgements will bear potential subjectivity biases depending on the respondents' preferences and needs for the information provided. Despite those shortcomings of human biases, and due to the lack of reliable quantitative data, the main stream of economic/business related methods to assess value of information has been based on the commonly known approach of contingent valuation, including Willingness-to-Pay (WTP) and Willingness-to-Accept (WTA) methods (Kenkel and Norris, 1995; Hudson and Hite, 2003; Marra et al., 2010; Rollins and Shaykewich, 2003), while several studies focused on applying it to agricultural production specifically (Diafas et al., 2013; Wang et al., 2003; Bontems and Thomas, 2000; Tice and Clouser, 1982).

The study by Kenkel and Norris (1995) was a first attempt to determine willingness-to-pay of Oklahoma agricultural producers for mesoscale weather data and related agricultural decision aids. The authors found that farmers were willing to pay a mean of $5.83/month for raw weather data and a mean of $6.55/month for raw data plus value-added information (tools). Accordingly, the authors estimated the total WTP to amount to $29,942/month (for raw weather data) and $186,364/month (for raw data plus value-added information) among Oklahoma farmers, which can be translated to the value of information provided by the Oklahoma Mesonet. Adjusting the values for inflation since 1995 (2.24% based on the Consumer Price Index Inflation Calculator)[1], the estimated annual values of Mesonet information would represent $48,377.15 and $301,107.43, respectively, as of January 2017. Also, Penn and Kasulis (2000) interviewed 515 farmers (both Mesonet users and non-users in Oklahoma) and evaluated, among others, their WTP for Mesonet weather information at the median value of $40/month for non-users and $30/month for Mesonet users as of 2000. The collected data was applied to derive a potential value of information provided by the Oklahoma Mesonet.

Despite a wide applicability of contingent valuation and the WTP

[1] https://www.bls.gov/data/inflation_calculator.htm

approach to many disciplinary problems, the method has also been criticized for subjectivity reasons related to human assessments and a potential reactions to a question indicating a potential (even though not anticipated) user fee (Cohen and Zilberman, 1997; Kenkel and Norris, 1997; Choi and Ritchie, 2010). From the economic perspective, a *rational consumer* (maximizing their utility subject to a budgetary constraint) would underestimate his/her assessment in anticipation of a potential fee implementation for services they receive for free otherwise. Thus, the WTP approach might generate evaluation biases that are difficult to eliminate or prevent, and thus distort research results. Moreover, the differences in human perceptions about information might vary depending on historical, cultural, demographic, and socio-economic factors (Peppler, 2011; Smith et al., 2007; Gillespie and Mishra, 2011), making it even more challenging to address in regard to the subjectivity biases.

Many other studies addressed economic benefits of improved weather forecasts to agricultural producers for different crops and agricultural commodities with a multitude of evaluation approaches, including behavioral economics theory, stated-preference methods, and optimization approaches (Adams et al., 1995). For example, Klockow and McPherson (2010) took a conceptual path with 21 in-depth interviews to estimate the potential amount that could be saved if Oklahoma farmers were using Mesonet information for their fertilizer and pesticide applications. Katz et al. (1987) particularly focused on the value of precipitation forecasts for spring wheat farmers facing the 'fallowing/planting problem' in the western parts of the Northern Great Plains, affecting farmers' net returns from agricultural production as well as soil moisture. Also, value of information has been discussed in other disciplines, ranging from the effects of weather forecasts on the trucking industry (Nelson and Winter, 1964), labeling consumer products (Evans et al., 1988), impact of information about differences in gas prices on gasoline demand in urban areas (Marvel, 1976), risk assessment by insurers (Pauly, 1968), value of space-derived data for natural disasters (Williamson et al., 2002), geomagnetic storm forecasts (Teisberg and Weiher, 2000), and impacts of weather on housing prices (Rosen, 1976; Blomquist et al., 1988). The most recent literature analyzes value of information in stock market and business settings (Kao and Steuer, 2016; Garifova, 2015), risk assessment (Galanis, 2016), and improving cost-effectiveness of decision-making and policy alternatives (Dilokthornsakul et al., 2016; Memarzadeh and Pozzi, 2016).

This study uses a combination of the current market and utility value methodologies to quantify economic value of Mesonet weather information in Oklahoma's agriculture in 2006–2014. By means of the profitability analysis, this research considers the value of Mesonet weather information as an exogenous variable measured by monetary (tangible) benefits that can be derived from its application in the agricultural sector, based on current and past cash flows in the analyzed time frame. Thus, economic value of Mesonet weather information is defined here as a synonym of economic benefits in agricultural production gained from the application of Mesonet weather information. Those two terms will be used interchangeably throughout the paper.

## 3. Methods and data

The analysis included the most prevalent consumption dryland crops in Oklahoma: wheat, soybeans, sorghum, cotton, rye, corn, and oats. Although hay is an important crop in the state, it has not been considered in this analysis due to a multitude of hay varieties and missing consistent time series data. Similarly, livestock production was not considered, which would otherwise add to the total economic value Mesonet information generates for agricultural production. The analysis was based on data from the USDA NASS statistics for the entire state of Oklahoma and for the respective climate regions in 2006–2014. The following variables were derived: planted acres, harvested acres, average yield (bu/ac), and nominal crop price ($/bu). The prices for corn silage were based on University of Nebraska-Lincoln (2017) according to which corn silage in the field before harvest should be valued at 7.65 times the price per bushel of corn where a ton of corn silage is harvested at 60–65% moisture. All nominal values (crop prices and production costs) were converted to real prices to adjust for inflation and allow a more accurate year-to-year comparison. For this conversion, the Consumer Price Index for CPI-All Urban Consumers (CPI-U) from the Bureau of Labor Statistics for the analyzed time period was applied (US DoL, 2017).

According to the NASS database, production of some crops was discontinued in the drought years, and reinstated in the following years. In addition, data from the Oklahoma crop budgets was used that allowed to account for the average production costs per acre of planted crops and the total costs of the produced crops in the state. It needs to be mentioned, however, that the crop budgets provide only estimated/predicted costs per acre of production for each following year based on the current year production output and yields. They do not include an uncertainty (correction) factor in case of unexpected weather changes (e.g., droughts) that could cause considerable crop failures and decreased yields. Given the fact that the crop budgets are the only source of agricultural production cost estimates in the state, potential error factors need to be indicated in this context.

Based on the data, profitability analysis of farming operations was conducted to determine net returns as a calculation basis for the economic value of weather information provided by the Oklahoma Mesonet. Net returns were determined for the agricultural production output in the analyzed time period 2006–2014 as a difference between total production revenues and total production costs (Eq. (1)). They were calculated in the following way: 1) cumulatively for each crop in the entire state of Oklahoma, and 2) separately for each crop in each climate region. Revenues were calculated as a product of the crop yield, area of the harvested crop, and the market price for the crop in a given year. Costs were calculated as a product of unit costs of producing the crop and the area of the planted crop in the same year.

$$NR_i = (Y_i * Ah_i * P_i) - (C_i * Ap_i) \tag{1}$$

with:

$NR_i$ – net returns (profit) from producing crop $i$ [$]

$Y_i$ – yield from crop $i$ [bu/ac]

$Ah_i$ – area of harvested acres of crop $i$ [ac]

$P_i$ – market price for crop $i$ [$/bu]

$C_i$ – unit cost of producing crop $i$ [$/ac]

$Ap_i$ – area of planted acres of crop $i$ [ac]

Production yields and prices were generally expressed in bushels and $/bu, respectively. The units for sorghum were converted from (cwt = 100 pounds) to bushels (1 ctw[2] = 2.2 bu), while they were expressed in pounds (lb) for cotton and in tons (t) for corn silage. Total revenues for corn were calculated as a sum of revenues for corn grain and corn silage production.

Positive net returns indicate profitability, meaning that the total revenues generated from agricultural production outweigh total costs accrued with the production factors throughout the production process. Negative net returns indicate an output loss from agricultural production.

In the context of this analysis, both positive and negative values of net returns were considered to evaluate economic gains and prevented losses through the application of Oklahoma Mesonet information for all analyzed crops in Oklahoma and in each climate region separately. The inclusion of positive net returns stems from the premise of this paper to articulate benefits of Mesonet information. While Mesonet application

[2] cwt - centum weight

does not generate economic losses, it can help prevent losses due to weather, production factors or other external factors. For this reason, also negative returns were included in the calculation of the economic value as described below.

Net returns constitute a calculation basis for the economic evaluation of weather information provided by the Oklahoma Mesonet to farmers. The profits indicate the production value gained in a given year by farmers in the given weather conditions and with a given level of weather knowledge/information and application of production factors. While farmers use Mesonet information indirectly with the regional and state weather broadcasts (as described in Section 1), not all Oklahoma farmers use Mesonet in a direct (choice-driven) way (online or app services). This study focuses only on the direct use of the Mesonet information for farming purposes, while the indirect use could involve a future application of shadow price and opportunity cost analysis.

The net returns were adjusted by the 'profitability factors' (Factor P) describing the degree of benefits generated by the application of Oklahoma Mesonet information to agricultural production. Factor P was calculated based on information derived from a survey conducted with 42 farmers in different climate regions in Oklahoma in spring 2016 (Ziolkowska and Zubillaga, 2018).[3] The survey study determined the monetary impact (contribution) of Mesonet information on agricultural profits (in other words: the percentage of agricultural profit that could be attributed to Mesonet information) with a question about the value Mesonet information and data provide to the farm over the course of one year. The median estimate based on the survey responses was found to be \$1,000/year, while the average value amounted to \$11,948/year.[4] Those values were further used to determine the profitability adjustment factors (Factor P) in order to account for the net return share (in percent) that could be attributed to the direct use of Mesonet information in Oklahoma. Given that the average real net returns in 2006–2014 to the surveyed farmers amounted to \$27,082/year, Factor P = 3.7% and Factor P = 44.1% were estimated respectively as: a) a percent ratio of the median estimate of Mesonet contribution to farming profits (\$1,000/year) and the average net returns, and b) a percent ratio of the average estimate of Mesonet contribution to farming profits (\$11,948/year) and the average net returns.

Due to a small sample size, the standard deviation for the Factor P is high, which indicates a high variability in farmers' responses that has been partially accounted for by using the median instead of the mean for the following analysis. As this study is exploratory and behavioral at the same time, there is no standard level of Factor P that could be tested and accounted for uncertainty. Moreover, a larger sample size would not necessarily guarantee higher robustness of the Factor P as subjective assessments of the respondents might vary significantly even at higher survey response rates. However, a larger sample size might confirm stronger or weaker response variability. As correlations were not tested for the purpose of the profitability analysis, neither probability nor significance tests were necessary. However, the variability of the outcomes has been tested with a sensitivity analysis.

The scenario with Factor P = 3.7% will be used as a benchmark to represent the conservative contribution of Mesonet information to agricultural outputs. However, it needs to be remembered that any rate change (including the 44.1% average rate) would impact variability of potential Mesonet benefits for farmers. It also needs to be mentioned that the 3.7% value seems rather underestimated for the large size of agricultural output in the state; however, it cannot be validated methodologically due to: a) missing studies in this field, b) the small sample size in this study, and c) the calculation itself being based on a median value rather than the average value of incongruent farmers' assessments. The profitability adjustment factors were applied to net returns and not solely to revenues, which can be explained with the fact that Mesonet information is utilized by farmers both for improving agricultural output and reducing production costs.

Factor P was included in this analysis as an exogenous variable (and calculated as a percentage of net returns affected by the application of Mesonet information). Following the methodological approach of the net return analysis, it might conceptually seem more appropriate to include the value of Mesonet information as an endogenous variable i.e. input factor in order to determine the economic value of Mesonet with the shadow price approach. However, this proceeding is rather impossible as neither the quantity nor the price of Mesonet information can be specified (as they are unknown variables). While the 'quantity' of information applied by farmers has no unit and cannot be determined, the price of Mesonet information equals zero as it is freely available to the public. For those reasons, the only way of determining the value of Mesonet information was through an indirect way of accounting it as a percent of the production net returns.

As no data or studies exist about potential variations in regional monetary assessments, the same profitability adjustment factors were applied to correct the total net returns in the respective climate regions. While this is not a perfect approach, limited representation of farmers from each climate region in the survey study did not allow for a more region-focused estimation of regional probability factors. The regional variability in the agricultural net returns attributable to Mesonet information application was thus defined as a function of agricultural output and production costs, corrected by the uniform profitability adjustment factor and the number of farmers using Mesonet information for their farming operations. We recognize that the value of weather information is expected to vary by crop and over time due to weather variability and the scope of Mesonet applications by farmers (i.e., demand for information). However, as there is no information market (and thus no information price), a direct validation of this statement is impossible at this point of time. In addition to data paucity, this study is a first attempt to quantify value of information resulting for farmers from the Oklahoma Mesonet application, and thus assumptions and generalizations were inevitable. Therefore, in this specific case, the profitability factors were linearly applied to all crops and across the analyzed period, which consequently does not account for regional and temporal weather variability, which otherwise should be accounted for if data availability allowed for this specification.

In a next step, 'Factor U' was determined indicating the percent of farmers utilizing Mesonet information and value-added tools. The number of farmers using Mesonet in a direct way in their farming operations is unknown statistically as no data has been collected neither at the state nor regional level. Thus, for the purpose of this analysis, the percentage of farmers with knowledge of Mesonet and directly applying Mesonet weather information and tools was again derived from the survey results and found to be 73%. Factor U is an indicator of the share of agricultural production positively impacted by farmers' access to Mesonet weather information. The methodological process of the analysis is displayed in Fig. 2.

Finally, the total economic value of Mesonet information for each climate region was calculated as a sum product of regional net returns for all crops produced in the respective regions, Factor P, and Factor U, according to the Eqs. (2) and (3):

[3] Although the sample size is small for Oklahoma agriculture, the response rate to the survey (29%) was comparable with other studies in this field [(Klockow and McPherson (2010) interviewed 21 farmers, while the response rate to other survey studies was similar: 17% (Marra et al., 2010), 28% (Kenkel and Norris, 1995), 34% (Giangola, 2012)]. The response rate may also have been affected by farmers' field operations during spring and summer, which coincided with the timing of this survey. It also needs to be emphasized that the survey response rates are generally lower than interview response rates.

[4] This value (and the information provided by the farmers through the survey) does not allow for differentiations among different crops in the state of Oklahoma, though regional and crop-related production variations exist. To the author's knowledge, no other information is available (either literature-based or experimental data) in this field to be able to account for crop-related variability in regard to Mesonet application.

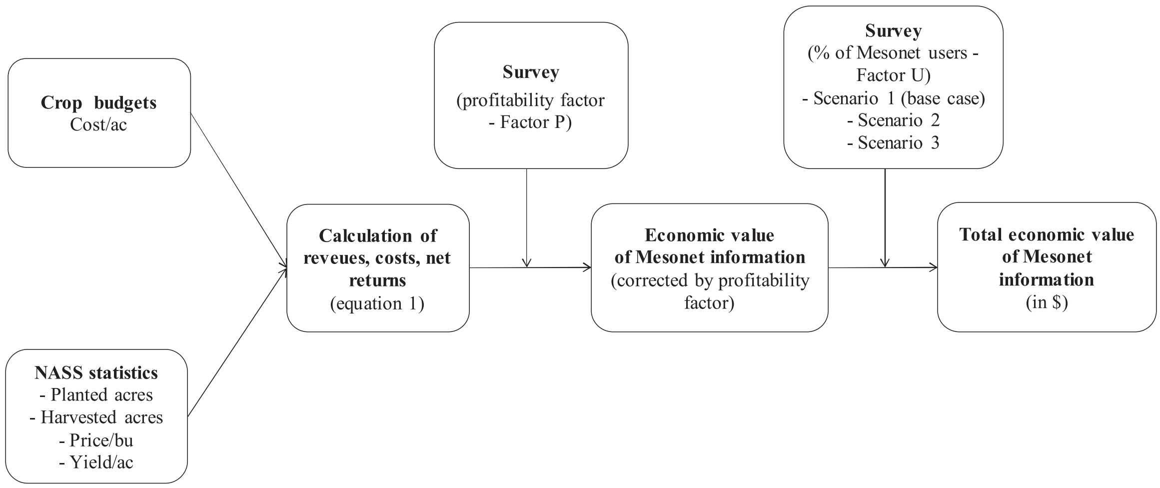


**Fig. 2.** Flow diagram of methodological proceeding to assess economic value of Mesonet weather information for Oklahoma agriculture.

$$V_{Ec} = \sum_{i=1}^{n} [\ |NR_i|^* \ Factor\ P * Factor\ U] \tag{2}$$

with:

$V_{Ec}$ – Total economic value (total benefit) of Mesonet information [$]
*Factor P* – Profitability factor [in %]
*Factor U* – Percent of farmers utilizing Mesonet information
such that:

$$V_{Ec} = \begin{cases} V_{Ec} > 0 \ iff \ NR_i > 0, \ \textit{improved profits from applying Mesonet information} \\ V_{Ec} \le 0 \ iff \ NR_i \le 0, \ \textit{prevented losses due to application of Mesonet information} \end{cases} \tag{3}$$

In case of the breakeven production point ($NR_i = 0$) it is difficult to determine the direct effect of Mesonet information on net returns as Mesonet value is included as an exogenous variable as described above. A breakeven point is also considered hypothetical in real production settings aimed at maximizing profits, however it is relevant to mention in this context.

The results of the profit adjustment present a base case scenario (scenario 1) with net returns corrected for the percent of farming operations utilizing Mesonet information directly (Factor U = 73%) and the profitability factor (Factor P = 3.7%) describing the perceived contribution of Mesonet information to farms' profitability. Two more scenarios were calculated based on the utilization factor (Factor U) assuming that 50% (scenario 2) and 30% (scenario 3) of all farmers in Oklahoma use Mesonet weather information in a direct way, while the profitability factors were kept in place for all the scenarios.

Farming profits will vary subject to changes in the variables determining production revenues and costs as specified above. Thus, it needs to be emphasized that the changes in net returns, and finally the economic value of Mesonet information each single year will highly depend on crop prices, planted and harvested acres of each crop in each year, costs of production factors, and total crop production outputs that are constantly influenced by market and weather variations.

## 4. Results and discussion – economic value of Mesonet weather information for agricultural production

### 4.1. Economic value of Mesonet information for state-wide agriculture

The results show the economic value (expressed with net returns from agricultural production) that can be attributed to the application of Oklahoma Mesonet weather information. In other words, it can be stated that the application of Mesonet weather information and tools contributed to the gain of those profits in the agricultural sector or helped prevent losses in agricultural production. The total benefit could also be interpreted as a sum of potential farming losses in a case if weather information from Oklahoma Mesonet was nonexistent.

Table 2 shows improved profits, prevented losses, and the total benefit of Mesonet weather information in all three scenarios and a wide variability over the analyzed time period 2006–2014. In the base case scenario, considered as the most accurate representation of the real-world situation as presented in this study, the highest economic

**Table 2**
Improved profits, prevented losses and total benefits (economic value) of Mesonet information in Oklahoma in different scenarios (Factor P = 3.7%).

| | Improved profits ($) | | | Prevented losses ($) | | | Total benefits ($) | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | 73% | 50% | 30% | 73% | 50% | 30% | 73% | 50% | 30% |
| 2006 | 550,009 | 376,719 | 226,031 | (13,526,227) | (9,264,539) | (5,558,723) | 14,076,236 | 9,641,258 | 5,784,755 |
| 2007 | 4,463,805 | 3,057,401 | 1,834,440 | (8,181,958) | (5,604,081) | (3,362,448) | 12,645,763 | 8,661,481 | 5,196,889 |
| 2008 | 11,962,332 | 8,193,378 | 4,916,027 | (1,727,448) | (1,183,183) | (709,910) | 13,689,780 | 9,376,562 | 5,625,937 |
| 2009 | 4,363,547 | 2,988,731 | 1,793,238 | (25,363,031) | (17,371,939) | (10,423,163) | 29,726,577 | 20,360,670 | 12,216,402 |
| 2010 | 7,616,872 | 5,217,036 | 3,130,222 | (17,044,518) | (11,674,327) | (7,004,596) | 24,661,390 | 16,891,363 | 10,134,818 |
| 2011 | – | – | – | (27,466,933) | (18,812,968) | (11,287,781) | 27,466,933 | 18,812,968 | 11,287,781 |
| 2012 | 3,354,080 | 2,297,315 | 1,378,389 | (4,496,184) | (3,079,578) | (1,847,747) | 7,850,264 | 5,376,893 | 3,226,136 |
| 2013 | 5,566,099 | 3,812,396 | 2,287,438 | (16,919,757) | (11,588,874) | (6,953,325) | 22,485,855 | 15,401,271 | 9,240,762 |
| 2014 | 3,453,969 | 2,365,732 | 1,419,439 | (27,055,851) | (18,531,405) | (11,118,843) | 30,509,820 | 20,897,137 | 12,538,282 |
| **Sum** | **41,330,713** | **28,308,707** | **16,985,224** | **(141,781,905)** | **(97,110,894)** | **(58,266,536)** | **183,112,618** | **125,419,601** | **75,251,761** |

Note: Prevented losses are noted with a negative sign (i.e., in brackets) due to the 'loss' designation; they are accounted as a positive value in the 'total benefit' of applying Mesonet information and products.

benefits to agricultural production from Mesonet weather information in Oklahoma through improved profits occurred in 2008 ($11.9 million) and in 2010 ($7.6 million). The highest prevented losses have been confirmed for the years of the most severe droughts in the state, $27.5 million in 2011, $27.1 million in 2014, and $25.4 million in 2009. The highest total benefits (as a sum of improved profits and prevented losses) were accordingly found in 2014, 2009, and 2011 with $30.5 million, $29.7 million, and $27.5 million, respectively. The total value over the analyzed time span of nine years was estimated at $183.1 million, with an annual average of $20.3 million for the entire state and the analyzed crops.

The highest and lowest values during the analyzed time span closely correspond with the drought events in the state (e.g., 2009, 2011, and 2014), and the recovery periods - normal wet years. As agricultural production is strongly impacted by weather, and determined by other market changes, the net returns from agricultural production vary accordingly. Consequently, the seasonal variations are observable in the economic benefits generated by the use of Oklahoma Mesonet information. Due to cyclically occurring droughts in the states, economic benefits resulting from Mesonet application were found to pertain more frequently to prevented losses than to benefits from additional profits.

In order to better understand the variability in the results, it is important to differentiate between temporal variations in different scenarios. The results are adjusted by the percentage of farmers using Mesonet information for agricultural production. Accordingly, the total economic benefits generated by the application of Mesonet weather information (through improved profits and prevented losses) ranged from $5.4 million in 2012 to $20.9 million in 2014 (scenario 2), and from $3.2 million in 2012 to $12.5 million in 2014 (scenario 3). The cumulative economic benefits from using Mesonet weather information for agricultural production of all analyzed crops across Oklahoma in 2006–2014 equaled $183.1 million (scenario 1), $125.4 million (scenario 2), and $75.2 million (scenario 3).

The annual variability in the results was influenced by large variations of the net returns for each single crop in Oklahoma in 2006–2014 (Fig. 3). While most crops indicated varying net returns over time, it is only wheat that showed significant economic losses in 2009–2011, and in 2013-2014. Those developments can be directly explained with the drought events in the state resulting in small planted areas and extremely low yields. Even though crop prices increased by 200% for oats and rye in 2011 (compared to 2006) and 150% for wheat, they did not leverage for economic losses due to the decrease in agricultural production output. The significant variability in net returns in agricultural production was also confirmed and validated by other research studies. For instance, Barta et al. (2015) found that the average market value of sales per farm, for all agricultural products in Oklahoma was $88,848, while the average expense for total production per farm was $60,340. Accordingly, net cash farm income showed that 62.05% of farms experienced a loss in 2012 alone.

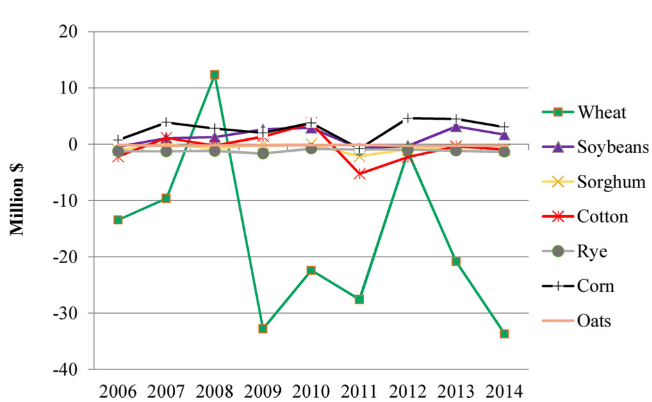


**Fig. 3.** Annual net returns for the analyzed crops in Oklahoma in 2006–2014 with Factor P = 3.7%.

When estimating economic value of Mesonet information at the state and regional level, it is important to analyze how the value and benefits generated by Mesonet information changed subject to simultaneous variations in the base case variables. Specifically, the base case scenario indicates a situation with Factor P = 3.7% and 73% farmers using weather information from the Oklahoma Mesonet. However, as the number of farmers applying Mesonet information (and thus the percent of agricultural production relying on Mesonet) across Oklahoma is not known precisely, a sensitivity analysis was conducted to validate the results in the base case scenario. The sensitivity analysis provides a broader insight into variability of economic benefits from Oklahoma Mesonet subject to a stepwise change from 10% to 100% for Mesonet users and 1% to 10% in the profitability factor, based on the cumulative total benefit generated in Oklahoma in 2006–2014 ($6.7 billion comprising both profits and prevented losses without any corrections with Factor P and Factor U) (Table 3). Thus, for instance, starting from the base case value, and assuming a 5% profitability factor as a contribution of the Oklahoma Mesonet to agricultural production and 50% farmers (and farming operations benefiting from Mesonet weather information in a direct way), the total benefit from Mesonet information would amount to $169.4 million. Furthermore, with an increasing profitability factor and the percent of agricultural production benefiting from Mesonet weather information, the economic benefits are increasing stepwise reaching $677.9 million in a hypothetical scenario assuming that all farmers in Oklahoma were direct Mesonet users and 10% of their farm profitability depended on this information. The sensitivity analysis shows that the incremental changes in the scenario variables have a validated impact on the final results, which proves the robustness of the analysis.

### 4.2. Economic value of Mesonet information in different climate regions

As discussed in section 1, agricultural production in different parts of the state can vary considerably, among others, due to changing weather conditions. Therefore, it is relevant to analyze the economic value of Oklahoma Mesonet information in the respective climate regions to detect this regional variability. Fig. 4 indicates the highest economic values (and benefits from using Mesonet weather information) in the Southwest, the North Central region, and in Panhandle, regardless of the analysis scenario, which can be explained with the net revenues from agricultural production. In the base case scenario 1 (Factor P = 3.7% and Factor U = 73%), the highest total cumulative benefits in 2006–2014 reached $45.9 million in the Southwest, $38.2 million in the North Central region, and $34.5 million in Panhandle. In a more conservative scenario 2, the benefits amounted to $31.5 million in the Southwest, $26.2 million in the North Central, and $23.6 million in Panhandle. The highest estimated economic benefits in the Southwest can be attributed to prevented losses from wheat and cotton production (rather than to production gains). In many instances, the area of planted acres of those crops significantly exceeded the area of harvested acres in this region, thus causing the total production costs outweigh production revenues. Moreover, those three regions are characterized by relatively low rainfall levels (compared to other regions in the state), but where agricultural production plays the most important role in the regional economies. With a changing geographical location towards the east, the economic value of Mesonet information in the analyzed regions decreases. This confirms the actual situation and lower importance of agricultural production corresponding with lower application rates of Oklahoma Mesonet weather information in the eastern parts of the state. The economic benefits generated by the application of the Oklahoma Mesonet information to agricultural production in the other climate regions were above the $6 million mark in 2006–2014 (West Central, Central, and South Central regions) and below this mark in the remaining Oklahoma climate regions.

Moreover, annual variations in agricultural production in the

**Table 3**
Sensitivity analysis for economic benefits of Mesonet weather information subject to changes in the profitability factor and % of farmers using Mesonet (Factor P = {0.01-0.1}).

| in million $ | **Profitability factor (Factor P) (in %)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **% farmers (Factor U)** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |
| **10** | 6,779,438 | 13,558,876 | 20,338,314 | 27,117,752 | 33,897,189 | 40,676,627 | 47,456,065 | 54,235,503 | 61,014,941 | 67,794,379 |
| **20** | 13,558,876 | 27,117,752 | 40,676,627 | 54,235,503 | 67,794,379 | 81,353,255 | 94,912,131 | 108,471,006 | 122,029,882 | 135,588,758 |
| **30** | 20,338,314 | 40,676,627 | 61,014,941 | 81,353,255 | 101,691,568 | 122,029,882 | 142,368,196 | 162,706,510 | 183,044,823 | 203,383,137 |
| **40** | 27,117,752 | 54,235,503 | 81,353,255 | 108,471,006 | 135,588,758 | 162,706,510 | 189,824,261 | 216,942,013 | 244,059,764 | 271,177,516 |
| **50** | 33,897,189 | 67,794,379 | 101,691,568 | 135,588,758 | 169,485,947 | 203,383,137 | 237,280,326 | 271,177,516 | 305,074,705 | 338,971,895 |
| **60** | 40,676,627 | 81,353,255 | 122,029,882 | 162,706,510 | 203,383,137 | 244,059,764 | 284,736,392 | 325,413,019 | 366,089,647 | 406,766,274 |
| **70** | 47,456,065 | 94,912,131 | 142,368,196 | 189,824,261 | 237,280,326 | 284,736,392 | 332,192,457 | 379,648,522 | 427,104,588 | 474,560,653 |
| **80** | 54,235,503 | 108,471,006 | 162,706,510 | 216,942,013 | 271,177,516 | 325,413,019 | 379,648,522 | 433,884,026 | 488,119,529 | 542,355,032 |
| **90** | 61,014,941 | 122,029,882 | 183,044,823 | 244,059,764 | 305,074,705 | 366,089,647 | 427,104,588 | 488,119,529 | 549,134,470 | 610,149,411 |
| **100** | 67,794,379 | 135,588,758 | 203,383,137 | 271,177,516 | 338,971,895 | 406,766,274 | 474,560,653 | 542,355,032 | 610,149,411 | 677,943,790 |

respective climate regions (as a result of changing weather conditions and severe weather events) directly translate into the application frequency of Mesonet information and finally the resulting economic value/benefits. Fig. 5 shows regional and temporal variations in the generated profits, prevented losses, and the total benefits generated for agricultural production in Oklahoma climate regions in scenario 1.

The Southwest region indicated the highest economic benefits (mainly through prevented losses) derived from Mesonet weather information in 2011 and 2014 equal to $8.8 million and $7.4 million, respectively. A similar trend was found for the West Central climate region, at a lower level of economic benefits ($4.5 million, respectively). In Panhandle, two distinct spikes in economic values were detected in 2013 and 2014 ($7.0 million and $5.5 million, respectively). The Northeast, East Central, South Central, and Southeast climate regions indicated economic benefits at much lower levels than in the other regions. They reached the levels below on average $1 million annually, which can be directly explained by a lower importance of agricultural production and a lower scale of Oklahoma Mesonet application.

The largest prevented losses both in terms of monetary values and in terms of their temporal frequency (recurrence) were found in Southwest, North Central, and West Central regions. Prevented losses were relatively very low in Northeast, East Central, and Southeast, which directly corresponds with the precipitation patterns and low concentration of agricultural production in those parts of the state.

Accounting for the higher profitability factor (Factor P = 44.1%) would results in accordingly higher benefits distributed locally.

## 5. Conclusions

This study estimated economic value of weather information provided by the Oklahoma Mesonet for agricultural production in the state. The results revealed that the cumulative benefits for agricultural production from applying Mesonet weather information (comprising generated agricultural profits and prevented losses) amounted to ~$183.1 million for all analyzed crops across Oklahoma in the analyzed time period 2006–2014. While this value represents the base case scenario results (profitability factor = 3.7%, i.e., 3.7% of agricultural production output was attributed to the application of Mesonet information, and given 73% of farmers are Mesonet users), results from other scenarios vary accordingly. Regardless of the scenario, the highest economic benefits from Mesonet weather information were detected in 2014, 2009 and 2011, and can be explained as a direct outcome of severe droughts impacting agricultural production and prevented losses due to the application of Mesonet value-added products and information. Moreover, a regional analysis for all nine climate regions in Oklahoma showed the highest cumulative benefits in 2006–2014 in the Southwest ($45.9 million), North Central region ($38.2 million), and in Panhandle ($34.5 million) in the scenario assuming that 73% farmers are Mesonet users. Also, high temporal variations were found for all regions.

If alfalfa hay and livestock production were considered, the value of Mesonet weather information would go up considerably. Furthermore, the cost for crop production per acre in this study refers to dryland crops due to data availability from the Oklahoma crop budgets. Thus, if irrigated crops were considered, production costs might turn higher and could potentially reduce profits to some extent. Given that profits were

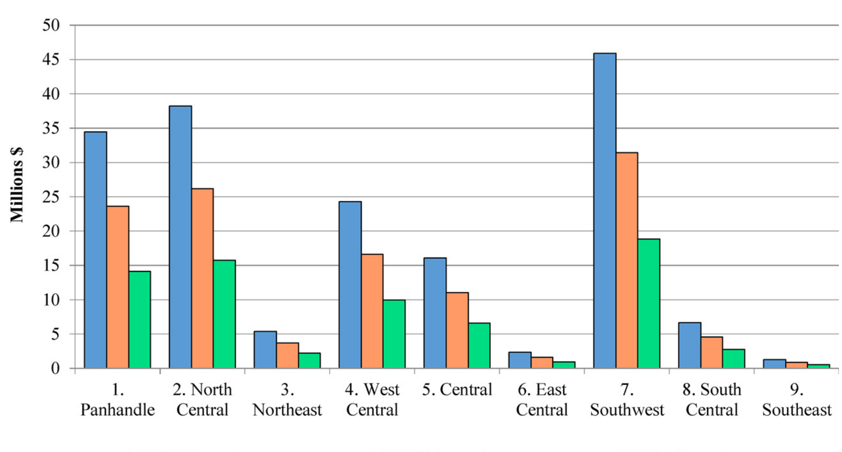


**Fig. 4.** Cumulative economic benefits expressed in net returns from using Mesonet weather information in Oklahoma climate regions (2006–2014) with Factor P = 3.7% in three scenarios.

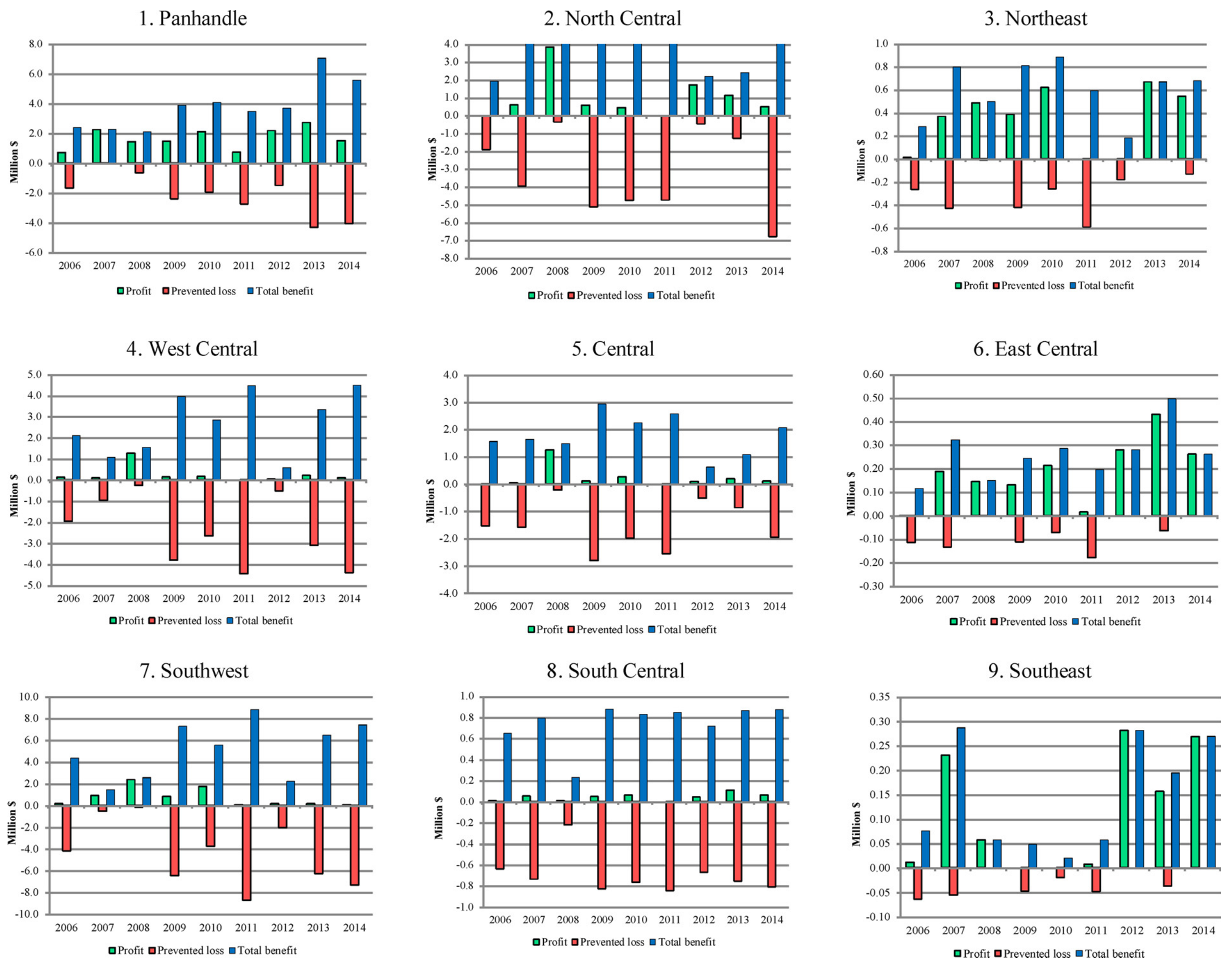


**Fig. 5.** Profits, prevented losses, and total benefits (economic value) from Mesonet information application in Oklahoma climate regions in scenario 1 (Factor P = 3.7%).
Note: Prevented losses are displayed with negative red bars due to the 'loss' designation; however, they are accounted as a positive value in the 'total benefit'.

negative for several crops over the analyzed time span, the application of dryland costs is not detrimental, but rather a more realistic measure of the market situation (especially because of the frequent droughts in the state in the recent decade).

Under the assumptions of this analysis, it was found that in the years of extreme and exceptional drought (2006, 2008–2009, and 2011–2014) Mesonet information and tools hold a higher importance and weight in preventing agricultural production losses than in improving profits per se. This statement can be verified with patterns occurring in Panhandle, the North Central, West Central, Central, and Southwest regions. Therefore, also for this reason, it is more difficult to pinpoint and quantify the economic value of prevented losses which are not manifested directly (as they have been prevented from occurring) as compared to increased profits (which can be easily tracked through farm accounting records). In normal years, the extent and degree of prevented losses compared to additional profit generation varied depending on the geographic region. Furthermore, in some regions, economic benefits from the generated production profit as a result of Mesonet application for the most part outweigh the benefits of prevented losses regardless of weather anomalies, e.g., in the East Central, Northeast, and Southeast regions.

While the presented method depends on highly variable factors (like market prices), there is currently no generally accepted approach to measuring value of information (Moody and Walsh, 1999). One of the barriers to developing a common, reliable, and suitable approach is the fact that information as an economic good is not well understood, while it follows the same economic laws as other material assets, which makes it difficult to apply in conjunction with traditional valuation methods used for other tangible resources.

While estimating economic value of information it also needs to be emphasized that information can be used for current decision-making, but it also presents a relevant data source for future applications. Similarly, by determining past trends, predictions can be made about future developments. Information can also be used by many groups due to its spillover effects. Thus, Mesonet information available to farmers allows them to optimize their production output, increase yields, which directly impacts market supply of agricultural products and determines the market price, subject to the demanded quantity. Thus, farmers' access to reliable and updated weather information will resonate on the food market sales prices, and directly impact consumers.

While accounting for information is difficult due to the intangible characteristics of information as such, quantifying the value of information can be helpful for many purposes, for instance:

- Improving awareness of the value of information as an organizational asset and its impacts on economic and social welfare. If information (or any other resource) is not quantified, it will generally be valued less than resources that are quantified. As information does not appear on the balance sheets, it is consequently undervalued, which can be explained with the limited number of research studies addressing economic value of information.
- Improving cost-effectiveness of resource use. In most cases, collecting, storing, analyzing, and maintaining information require high costs and time inputs that are not quantified. Measuring value

of information by means of the methodology applied in this paper could help determine the costs of the generated information and the value of investments in a more accurate way. This can further support management and organizational tasks to ensure that resources are being used in a cost-effective manner. Subsequently, this could also help reduce waste (e.g., through collection of redundant or unused data) (compare: Moody and Walsh, 1999).

Further research and accurate databases are necessary to account for the economic value of Mesonet information and benefits it provides to the society and different user groups and market agents. This study presented a first attempt to holistically and quantitatively estimate economic value of Mesonet information for agricultural production in Oklahoma. The outcomes can be used in further studies regarding other sectors and groups benefiting from Oklahoma Mesonet information.

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