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Quantification of agricultural drought occurrence as an estimate for insurance programs

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Abstract Temporal irregularities of rainfall and drought have major impacts on rainfed cropping systems. The main goal of this study was to develop an approach for realizing drought occurrence based on local winter wheat yield loss and rainfall. The domain study included 11 counties in the state of Washington that actively grow rainfed winter wheat and an uncertainty rainfall evaluation model using daily rainfall values from 1985 to 2007. An application was developed that calculates a rainfall index for insurance that was then used to determine the drought intensity for each study year and for each study site. Evaluation of the drought intensity showed that both the 1999–2000 and 2000–2001 growing seasons were stressful years for most of the study locations, while the 2005–2006 and the 2006–2007 growing seasons experienced the lowest drought intensity for all locations. Our results are consistent with local extension reports of drought occurrences. Quantification of drought intensity based on this application could provide a convenient index for insurance companies for determining the effect of rainfall and drought on crop yield loss under the varying weather conditions of semi-arid regions.

1 Introduction

Global drylands cover about 40 % of the earth's surface and are inhabited by 1.2 billion people who are mostly poor and food insecure (Hazell and Hess 2010). A more complicated situation is the fact that almost all of the major agricultural production areas are located on these lands (USDA 1994). Indigenous knowledge through history has developed extensive adaptive farming techniques to enable farmers to survive irrespective of the weather shocks (Bharara and Seeland 1994). However, increasing demand for water along with expansion of both agricultural and industrials sectors has resulted in water scarcity almost every year in many parts of the world (Lashkari and Bannayan, 2013). Droughts occur in all climate zones including high and low rainfall locations. Drought, depending on its intensity, could impact many sectors of the society and might also reach beyond the area that experiences a drought (Wilhite 2000). These impacts have been particularly harsh in developing countries where both the human and economic loss can be shocking and financial resources are limited (Araya and Stroosnijder 2011). Farmers have tried to prevent or mitigate the impact of drought on agricultural production by increasing the diversity of cultivated crops, cultivation of resistance crop varieties (Serraj et al. 2011) or other management factors (Lashkari et al. 2012). However, there are high levels of uncertainty and some controversy about the performance and cost of these methods (Rosenzweig and Binswanger 1993; Barnett and Mahul 2007). Moreover, these strategies may not be available to all households (Skees and Barnett 2006).

Intensive droughts have been observed on all continents (Le Comte 1995). During the last two decades, the impacts of drought in the USA have significantly increased in both the number and severity of drought occurrence (Mishra and Singh 2010). The impact of the 1988 large area drought on the US economy has been estimated ($40 billion) as two to three times the estimated loss by 1989 San Francisco earthquake (Riebsame et al. 1990). From 1980 to 2003, drought disaster costs in the US were $144 billion, which indicates that drought is the costliest natural disaster to strike the USA (Cook et al. 2007, Mishra and Singh 2010). In many parts of

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the world also due to water scarcity, production of rice, maize, and wheat has substantially declined in the past few decades (Bates et al. 2008). Rainfed agriculture, which is regularly exposed to drought, plays a leading role in providing food and livelihoods for an increasing world population, particularly in arid environments (Bannayan et al. 2010; Rockstrom et al. 2010; Araya and Stroosnijder 2011). Rainfall variability has been reported to have a momentous effect on the economy of dry countries and their associated food production (Bannayan et al. 2011a). There have been reports of rainfall variability and drought associated with food shortages (Araya and Stroosnijder 2011). In the semi-arid regions, it is not only the amount of rainfall that is the limiting factor of crop production but rainfall distribution also plays vital role on final crop yield determination (Segele and Lamb 2005; Bannayan et al. 2011b).

Drought is a prolonged, abnormally dry period of insufficient water to meet normal needs and demands. Generally, such events occur when a region receives consistently below average precipitation. It can have a substantial impact on the ecosystem and agriculture of the affected region. Although drought can persist for several years, even a short, intense drought can cause significant damage and harm to the local economy (Oliver 2005). The definition of drought requires a tool to analyze drought intensity for a given period of time. Such a tool or application should be able to quantify any association between drought intensity and any system component like final crop yield. Such an appraisal provides an estimate of agricultural products loss due to intensity of drought. A number of different indices have been developed to quantify drought. However, a simple tool which has the privilege of least requirement of the weather data can help with the detection and characterization of a drought intensity which can then be used for many rural areas across the world. Such an application would be more advanced if it was enabled with daily threshold of rainfall along with precise definition of the rainy season. Rainy season based on daily threshold of rainfall can be obtained as the output of the Uncertainty Rainfall Evaluation Model. This application could represent different classes of drought severity and could be linked to drought response for any required estimate of drought impact (Steinemann 2003; Shukla et al. 2011).

Rainfed agriculture is and will remain the dominant source of staple food production and the livelihood foundation of the majority of the rural poor. Production uncertainty associated with between- and within-season rainfall variability (Bannayan et al. 2010) remains a fundamental constraint to many investors. Information, tools, and approaches are now available that allow for characterization and mapping of the agricultural implications of climate variability and the development of climate risk management strategies specifically tailored to stakeholders needs (Cooper et al. 2008). Weather insurance index is being used by insurance agencies to evaluate and respond to drought (Deng et al. 2008; Patt et al. 2010; Díaz Nieto et al. 2010). Weather-based insurance index has showed promise as an efficient approach for managing drought risk in dryland areas but is still at an early stage of development (Barnett and Mahul 2007; Hazell and Hess 2010). Innovations in insurance for natural disaster risk are critically important to help the rural poor to improve their lives and to contribute to the overall economic growth in lower income countries (Skees et al. 1997). Using an index for insurance to address catastrophic risk can serve as the foundation for the development of broader financial services by removing one of the major constraints to market development (Skees and Barnett 2006). A rapidly increasing variety of tools and processes are being developed to improve decision making, reduce risks, and generate opportunities associated with climate variability and change. Different applications and tools and methods of agricultural insurance have been employed in different parts of the world for evaluation of drought effects on agricultural products specially rainfed cereals production (Cardenas et al. 2007; Skees et al. 2008). The methods and tools used for impact, vulnerability, and adaptation assessment encompass a broad range of applications (e.g., climate models, scenario-building methods, stakeholder analysis, and decision-making tools) to specific sectors (e.g., crop or vegetation models) (Van de Steeg et al. 2009). However, a simple evaluation approach as an indicator system might be most useful and appropriate scale for decision making. Computer-based decision applications are primarily intended to identify climate related risks and may include social vulnerability information and assist in establishing priorities. They may also include economic analysis as part of the decision-making process (IISD 2007). Some of these applications create graphs and tables that allow experts to compare the relative strengths of adaptation strategies using both quantitative and qualitative criteria. Other applications are more generally aimed at supporting the decision and policy makers responsible for identifying and appraising the selection and implementation of adaptation measures, taking into account the institutions involved and affected when pursuing given adaptation options. The UNFCCC compendium provides a range of examples of these types of decision applications (UNFCCC 2008).

The focus of the present study was to develop a simple application which integrates the calculation of drought occurrence and intensity based on a calculated rainfall index using the rainfall pattern obtained by outputs of the rainfall uncertainty model.

2 Materials and methods

2.1 Study area and data set

Many agricultural production regions are highly susceptible to extreme weather events. As a case study, we selected 11 counties in the state of Washington (Table 1), mostly located in the eastern and central eastern part of the state (Fig. 1). Annual average precipitation across the state ranges from less than 25.4 cm to more than 381 cm with high precipitation areas mostly on the western slopes of the Cascade Mountains and the lowest precipitation in the east central interior of the state. Total precipitation during the past 10 years (1999–2008) has been at least 10 % below average in parts of Washington. Two major statewide droughts in 2000–2001 and 2004–2005 caused a total economic loss of $901 million (Shukla et al. 2011). In this area, the highest amount of precipitation occurs during the fall and winter months, with the months of November, December, January, and February being the wettest months. As total annual precipitation is so heavily dependent on precipitation during these months, during years when there is a substantial total precipitation deficit at the end of these 4 months, it is unlikely that the deficit can be compensated later in those years. Therefore, for any year, precipitation is very crucial for drought mitigation planning and management (Shukla et al. 2011).

As it is impossible to perform such a task for each farmer's field, a weather-based index for insurance can use the amount of precipitation recorded at local meteorological stations. Daily rainfall values for the study locations for 23 years (1985–2007) were obtained from the US National Weather Service COOP database (http://www7.ncdc.noaa.gov/IPS/coop/coop.html). Drought was determined based on observed county nonirrigated winter wheat yield and perceived precipitation for all locations. Historical grain yields of nonirrigated wheat across the study counties in Washington were obtained from USDA/NASS (http://quickstats.nass.usda.gov/) database (Table 2). For the selected counties, the cropping season for nonirrigated winter wheat on average ranges from September to July. Planting normally occurs from August to early September while the wheat crop is harvested in July and August.

Fig. 1 Study locations in the State of Washington, USA

2.2 Rainfall uncertainty evaluation model

The Rainfall Uncertainty Evaluation Model (RUEM 5) was introduced by Reiser and Kutiel (2008). This model was used to determine the beginning and ending of the rainy season based on the pattern of dry and rainy days for a location using the simple total annual or growing season rainfall. In this model, it is essential to identify the shortest rainy season, or the longest dry period throughout the year in order to preserve the continuity of the rainy season (Reiser and Kutiel 2008). In order to obtain this value, the Rainy Season Length (RSL) was

Table 1 Location of the weather station for each county and harvested wheat acreage in 2007

County	COOPID weather station	Lat	Long	Elevation (m)	Harvested area 2007 (ha)
Asotin (AS)	450294	46.19	−117.10	945	7163
Benton (BE)	454154	46.17	−117.19	252	32294
Douglas (DO)	451400	47.52	−120.32	207	67380
Columbia (CO)	452030	46.30	−118.11	592	26709
Garfield (GA)	456610	46.51	−117.52	853	22299
Grant (GR)	456880	46.91	−119.62	107	33791
Spokane (SP)	457938	47.41	−117.25	753	37636
Stevens (ST)	451395	48.10	−118.10	441	1416
Whitman (WH)	456789	46.69	−117.14	731	133263
Yakima (YA)	459465	46.37	−119.99	329	5099
Franklin (FR)	451691	46.42	−119.19	82	25293

Table 2 Average annual rainfed grain yield (kg/ha) for the study locations in the state of Washington, USA

Years	Whitman	Benton	Yakima	Douglas	Garfield	Columbia	Franklin	Stevens	Spokane	Grant	Asotin
1985	5587	1474	1976	2452	2572	4723	1976	2311	3437	1949	1788
1986	4817	1507	1581	2097	2941	4824	1601	3289	4455	2244	2639
1987	5051	2391	1648	2941	3899	4200	2525	3584	4884	2505	3336
1988	4200	2438	2499	3169	3504	6036	3055	4609	3396	3102	3068
1989	6036	1353	1842	1735	3551	4837	1621	3316	4636	1742	3088
1990	4837	1829	1293	2485	4200	4736	2324	4502	2659	2539	4060
1991	4736	924	1018	1547	3222	5366	1688	4629	3149	1882	2572
1992	5366	1346	1072	1949	2900	5735	1949	3825	4060	1608	1675
1993	5735	2083	1949	3350	2767	5554	3658	3021	3189	3423	4167
1994	5554	2177	1996	2767	4093	4870	2077	3892	4221	3135	3309
1995	4870	2686	1654	2606	2800	4917	2412	3711	2807	3189	3169
1996	4917	3088	1929	2606	5132	4723	3872	4388	4951	3584	4200
1997	4824	2579	2371	2820	4267	4629	3484	3262	3999	4395	3269
1998	3765	2311	1829	3102	4288	5587	2552	4140	4515	3470	3376
1999	4227	2090	1621	3055	3390	3376	1963	2773	3450	2646	2633
2000	4629	2217	1520	2881	4455	3490	2673	4348	4877	4234	3544
2001	4462	1802	844	3015	3490	4462	4000	4140	3852	2827	2324
2002	3778	1876	1755	2780	3591	3571	2743	3350	3906	3490	2418
2003	5159	2345	2881	3055	3209	3973	3124	3671	4683	4100	2492
2004	3551	1078	2592	3236	3792	4556	2850	3912	5192	3343	3055
2005	3765	2150	1340	3651	4468	4013	2982	4462	5272	3584	3517
2006	4696	1246	1963	3102	4167	3242	3290	3839	4535	4160	3108
2007	3591	1842	1949	2974	4777	4971	3432	3443	4194	3577	2713

calculated for each day of year as Starting Date Analysis (SAD) for all study years and weather stations using the following equation:

$$RSL = DAP_{90} – DAP_{10} \qquad (1)$$

In which RSL is the Rainy Season Length, DAP_{90} and DAP_{10} are the dates when 90 % and 10 % of annual rainfall was accumulated, respectively. The median of RSL was calculated for each day of the year and then the 365 median RSL values for all 11 locations were placed in a matrix of 11×365 and correlations between any possible pair of locations were calculated. Monthly data were used instead of the daily data for determination of the daily rainfall threshold for determination of the other rainfall variables such as dry days since last rain requires monthly data. The SAD was calculated using the difference between the minimum annual RSL (the shortest median RSL) and the median RSL of the first day of each month. Therefore, the SAD of the rainy season was set to the first day of the month, in which this difference was the smallest (Reiser and Kutiel 2008).

Determination of the accurate start of the rainy season plays a vital role in calculation of parameters which relate to rainfall regime including the selection of the optimum sowing period for rainfed agriculture, estimation of the potential growing season length, germination, and seedling emergence, and the likelihood of optimum growing conditions in arid and semi-arid environments (Golian et al. 2010). The minimum rainfall requirement for the beginning of any process which requires rainfall water can be defined as the required rainfall threshold. The Daily Rainfall Threshold (DRT) values ranged from 0.1 mm to realize wet day numbers (Tennant and Hewitson 2002) to 40 mm as landslide occurrence threshold (Corominas and Moya 1999). However, traditionally, 1.0 mm is used for most regions as a measurable quantity of rain, (Romero et al. 1998). Determination of accurate values for DRT may significantly impact drought occurrence and intensity for semi-arid regions. Instead of setting one fixed threshold for all study locations, a certain percentile of the total annual rainfall of the selected location will better represent and characterize the rainfall regime. A 1-mm threshold for a location means a different percentage of the annual rainfall in another, given that each location has its own rainfall regime. Therefore, the determination of the DRT should be related to the total percentage (Haylock and Nicholls 2000). The average of total rainfall was calculated based on both a value of 0.1 and 1 mm for DRT (Glade et al. 2000). The ratio between these two totals was calculated (Reiser and Kutiel 2009) and compared for all locations as follows (Fig. 2):

$$\text{Ratio} = \left(\frac{\text{Total}\left(_{\text{DRT}=0.1}\right)\right) - \text{Total}\left(_{\text{DRT}=1}\right)\right)}{\text{Total}\left(_{\text{DRT}=1}\right)\right)} \right) \times 100 \quad (2)$$

This ratio was calculated for all study locations (Fig. 2). These results quantify the percentage of the rainfall amount accumulated between these two thresholds. Similar to Reiser and Kutiel (2007), a ratio of 96 % of the total was analyzed in order to enable the inclusion of additional locations in future. To determine the appropriate DRT, the total was recalculated for all DRTs from 0.1 to 10.0 mm with increments of 0.1 mm for all study locations. The total obtained in this way is the main precipitation amount that characterizes a rainfall regime (Reiser and Kutiel 2009).

2.3 Rainfall index for insurance

For weather index insurance, an index should be used that is highly correlated with actual losses. In its simplest form, a weather index should consider a measure of weather variables, such as rainfall for any location over a defined period of time (Barnett and Mahul 2007). Based on wheat phenology and local rainfall patterns, the time interval of 14 days was selected as the minimum time duration for calculating cumulative values of rainfall for each time interval for all study locations across all historical years. The computation of the rainfall index for insurance was performed by determining the weighted mean values according to the correlation values between average yield and cumulative rainfall for each time interval of 14 days of wheat growth for all study locations from 1985 to 2007 (Table 3). Total available water for each location was calculated using the FAO56 method (Allen et al. 1998):

Table 3 Calculated weight values based on correlation percentage obtained between observed grain yield and accumulated rainfall at each 14 days time interval across all locations

Correlation percentage	Weight value
100 to 60	3
59 to 40	2
39 to 20	1
19≥	0.5

$$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r \quad (3)$$

Where TAW is total available soil water in the root zone (mm), θ_{FC} is water content at field capacity ($m^3\ m^{-3}$), θ_{WP} is water content at wilting point, and Z_r is rooting depth. The rooting depth for wheat was obtained based on the FAO56 method (Allen et al. 1998). The values for field capacity and wilting point for the selected counties were obtained from the National Resource Conservation Service (NRCS 2011). When rainfall on any given day was more than TAW, the county-scale calculated value of TAW was used instead of rainfall. It was assumed that water beyond the storage capacity will be lost and does not contribute to plant growth. Rainfall values that were less than DRT were removed for all study locations.

It is possible to assume that simple cumulative rainfall might not completely elucidate the relationship between final wheat yield and rainfall. A significant improvement in tracking the close relation between final wheat yield and rainfall can be obtained by assigning a specific weight to the different crop growth time during the growing season. Assigning the weight factors would be able to maximize the rainfall-crop

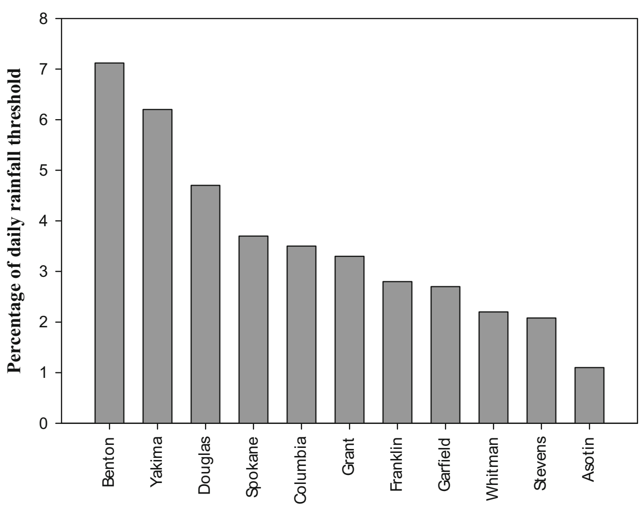

Fig. 2 The rainfall percentage that fell between DRT of 0.1 mm and DRT of 1 mm

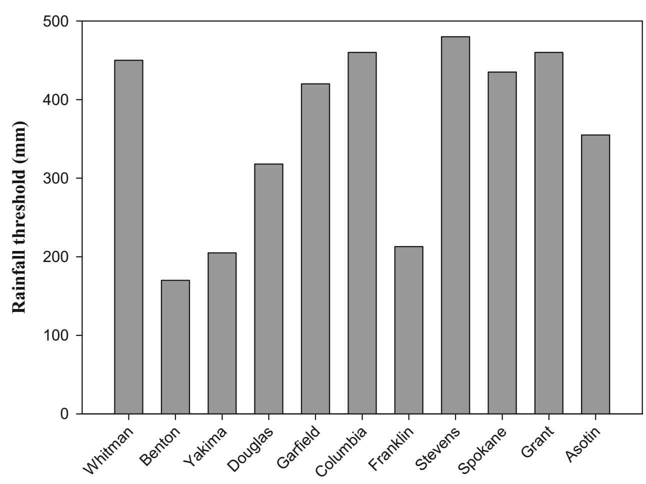

Fig. 3 Average of rainfall amounts (crop growth period) across study years as rainfall threshold

Table 4 Descriptive ranking of drought intensity values (based on Stoppa and Hess 2003)

Drought intensity value	Descriptive ranking
1 to 0.6	Extreme drought (ED)
0.59 to 0.10	Medium drought (MD)
0.09≥	Slight drought (SD)

final yield correlation which reflects the importance of the effect of rainfall on yield at a specific time span of crop growth. In order to obtain an appropriate and empirically significant number of weights, rainfall was aggregated in 14 days interval recognized to be consistent with water storage and plant use dynamics. Cumulative values of rainfall for 14 days intervals were calculated according to the average duration of the winter wheat growing season. It was also assumed that water in excess of storage capacity was lost and did not contribute to crop growth. The rainfall index was computed according to the rainfall index equation for all study years (Stoppa and Hess 2003):

$$R_t = \sum_{i=1}^{m} \omega_i r_{it} \tag{4}$$

Where m is the total number of 14-day intervals within the growing season for each individual county, ω_i is the weight (Table 3) assigned to period i of the growing season, and r_{it} is the effective rainfall in period i of year t. The average yield of rainfed wheat and total rainfall received during the growing season were calculated for each study location based on the data from 1985 to 2007. Then, the 10 years that achieved a yield level that was closest to the long-term average yield were selected. Thus, the average total rainfall during the cropping season across the selected 10 years was considered as the rainfall threshold (Fig. 3). Based on this approach, drought conditions for any given year occurred whenever the value for R_t value was less than the determined rainfall threshold during the crop growth period. However if R_t was more than the determined rainfall threshold then one would not be able to declare rainfall as the main reason for any crop yield loss. Such drought declaration requires an estimate of drought intensity. In this study, the drought intensity (DI) was calculated according to Stoppa and Hess (2003) as:

$$\mathrm{DI} = \frac{T - R_t}{T} \tag{5}$$

Where DI is the drought intensity (Table 4), T is the determined rainfall threshold and R_t is the rainfall index (Eq. 4). It is possible to calculate the insurance indemnity using the DI and contract premium (Martin et al. 2001; Stoppa and Hess 2003). The value of DI was determined for all study locations and for all years.

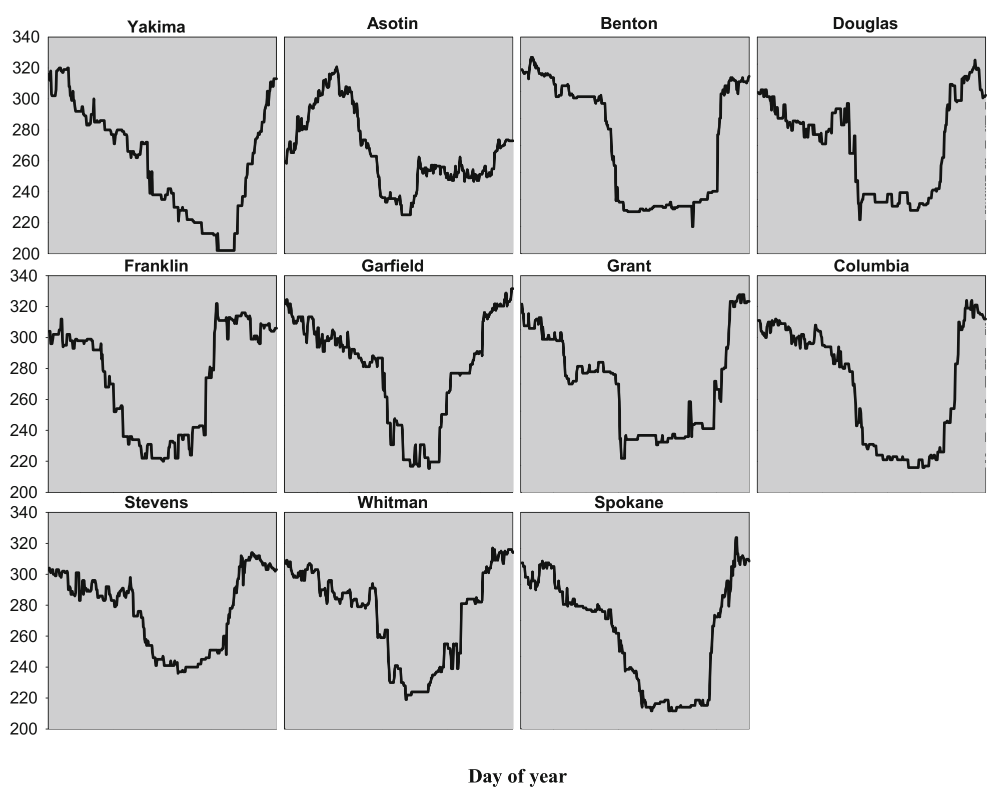

Fig. 4 The rainy season length (RSL) using different starting analysis day (SAD) in all study locations

3 Results

3.1 Rainfall uncertainty

Rainfall recorded in Asotin, Benton, Douglas, Columbia, Garfield, Grant, Spokane, Stevens, Whitman, Yakima, and Franklin counties showed a bi-modal annual pattern (Fig. 4). Such results could help to determine any conservative relation between similar rainfall pattern stations. In this order, a cluster analysis was also employed as multivariate analysis to classify the rainfall data recorded at each weather station by similarity in the annual change of the rainy season duration. The results from the cluster analysis showed that one cluster was classified by 60 % of similarity. Asotin, Benton, Douglas, Columbia, Garfield, Grant, Spokane, Stevens, Whitman, Yakima, and Franklin all classified in the same class. The clusters showed the regions that had similar climatic conditions with respect to rainfall.

The Starting Analysis Date (SAD) refers to the beginning of a new rainy season and characterizes a certain region, whereas, beginning date and the ending date determine the Rainy Season Length (RSL). The RSL was defined as the period that elapsed from the day on which 10 % of the annual rain was accumulated until the day when 90 % was accumulated. In order to find the shortest RSL, it was calculated for each individual day of year as the SAD and for every available year. The median RSL for each day of year was then calculated. The SAD was determined for each location (Fig. 5) to ascertain the start of the analysis for each location as defined in detail by Reiser and Kutiel (2008). According to this method, the beginning of the rainy season was August 1 for Asotin, Benton, Douglas, Columbia, Garfield, Grant, Spokane, Stevens, Whitman, Yakima, and Franklin counties (Fig. 5). Determination of SAD based on this approach determines a minimum possible continuous rainy season for any given location. The daily rainfall threshold ranged from 0.1 to 1.5 mm. Spokane had the highest value for DRT belonged (1.5 mm) (Fig. 6) and Benton, Grant, Stevens, and Yakima had the lowest value (0.1 mm) (Fig. 6).

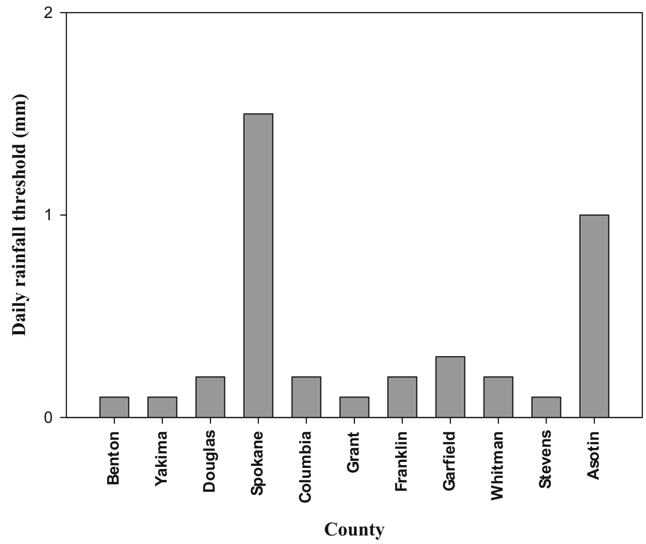

Fig. 6 The daily rainfall threshold (DRT), which was set to 93 % of the total rainfall for all locations

3.2 Rainfall index insurance

In order to show how the developed application is able to track any shortage of rainfall or drought occurrence, the projected drought occurrence as determined by the application for all historical years was compared with what has been reported as observed drought conditions for the same location. All WA study locations showed moderate and extreme drought conditions during the 1999–2000 and 2000–2001 growing seasons, especially the central east counties such as Grant (Table 5). In

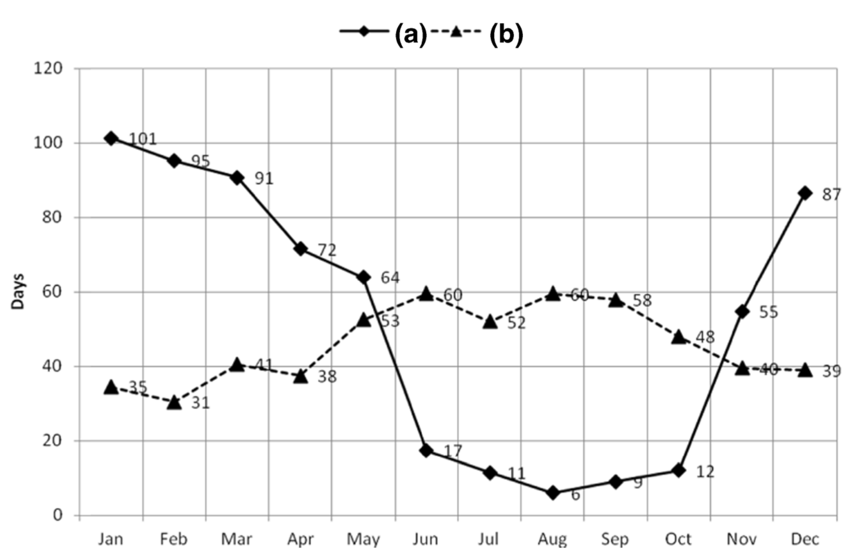

Fig. 5 Average differences between the shortest median rainy season length (RSL) and the shortest median RSL of the first day of each month

addition, moderate drought conditions continued until the 2004–2005 growing season for all study locations except Stevens and Whitman (Table 5). Drought occurrence and intensity values demonstrated that 2005–2006 growing season was without climatic drought for nearly all study locations of WA. Slight and nondrought conditions continued during the 2006–2007 and 2007–2008 growing seasons (Table 5).

The weather risk market is continuously evolving. The developed and proposed application requires the rainfall and final grain yield for any given study location which makes it quite feasible to be applied for any location for which only the minimum daily weather data are available. Based on the analysis of rainfall and rainfed wheat yield data across 11 counties within WA, our results indicated that our application based on a rainfall index could be applied in WA. However, finer resolution information (at farmer's fields) might improve the screening for the occurrence of drought. It should also be stated that the imperfect correlation between the realized production loss and considered weather variable/s may subject the results to some biases.

4 Discussion

A major objective of this study was to provide both farmers and insurance agencies a site-specific application and tool

Table 5 Descriptive ranking of drought intensity for each year and location

Growing season	Drought intensity	BE	YA	DO	SP	CO	GR	FR	GA	WH	ST	AS
1999–2000	ND											
	SD											
	MD	×	×		×	×		×	×	×	×	
	ED			×			×					×
2000–2001	ND											
	SD									×		
	MD		×		×	×		×	×		×	
	ED	×		×			×					×
2002–2003	ND										×	
	SD				×				×	×		
	MD	×	×	×		×		×				×
	ED						×					
2003–2004	ND									×		
	SD							×				
	MD	×	×		×	×			×		×	×
	ED			×								
2004–2005	ND											
	SD										×	
	MD			×	×			×	×	×		×
	ED	×	×			×	×					
2005–2006	ND		×		×			×		×	×	
	SD	×				×	×		×			
	MD			×								×
	ED											
2006–2007	ND								×	×		
	SD				×		×	×				
	MD	×	×	×							×	×
	ED					×						
2007–2008	ND											×
	SD		×		×		×	×	×	×		
	MD	×				×					×	
	ED			×								

ND no drought, *ED* extreme drought, *MD* moderate drought, *SD* slight drought, *AS* Asotin, *BE* Benton, *DO* Douglas, *CO* Columbia, *GA* Garfield, *GR* Grant, *SP* Spokane, *ST* Stevens, *WH* Whitman, *YA* Yakima, *FR* Franklin

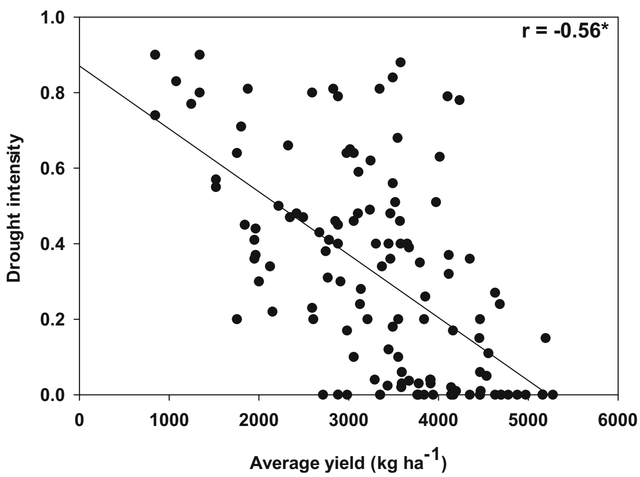

Fig. 7 Correlation between average yield of rainfed wheat and drought intensity values

that is based on rainfall above a daily threshold and recorded nonirrigated or rainfed winter wheat yield. To be truly useful, this application requires access to observed historical crop yield and rainfall data. All study locations showed a uni-model annual rainfall pattern. However, there was diversity in rainy season length across study locations. The starting date of the rainy season for all study locations was August 1. Similar to observations, the rainfall index based insurance showed drought occurrence and intensity across all locations in 1999–2001, 2002–2003, and 2007–2008 growing seasons. Therefore, this index was successfully implemented in our application for the determination of drought conditions for insurance companies. The results are more indicating owing to the fact that there was significant negative correlation between drought intensity values and average yield of rainfed wheat in all study locations (Fig. 7). There are a number of extensions to the approach outlined in this study which will make it useful for real-time drought assessment and decision making. This approach could be extended and other weather variables could be considered which might be more dominant for certain weather events that affect crop yield associate loss due to weather extremes, such as frost or heat. However, it is critical to develop a robust relationship between the weather variable and the production variable. A critical requirement for applying such application in here is the continued availability of high-quality daily weather data. Weather risks can also be linked to price fluctuations especially when the drought or other weather disaster is spatially broad. The next logical step to further improve our application is to include other weather variables and soil water as well and for the user to determine which weather variables have a dominant impact on yield loss selected location. Positive evaluation of the approach based on reported drought across the study locations may attract the interest of owners of various businesses using such weather variables for reducing their revenue fluctuation. Our results merit our approach for finding similar solution for trading that are exposed to weather risks within their industry.

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