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Soil Moisture and its Suitability for Winter Wheat and Cotton in Four-Lake Watershed of Hubei Province, China

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Abstract: Four-lake watershed, an important agricultural region in Hubei Province of China, is vulnerable to water-logging, using long-term observation to study influence of excessive water in soil on crop has an important significance for prevention of agricultural water-logging disaster and reasonable arrangement of agricultural production. In the study, duration and index of soil moisture excess are put forward and used to describe severity of farmland encountering subsurface water-logging. Based on analysis of 25 years of observational data, the results showed that winter wheat in spring and cotton from seedling to boll stage usually encounter a mild subsurface water-logging; generally subsurface water-logging seldom occurs in boll-opening period of cotton. In terms of typical years' analysis, no subsurface water-logging befell in general drought year, in normal year a phenomena of soil moisture excess doesn't exist in developmental stage of winter wheat and occurs in blossoming and boll-forming stages of cotton, which often leads to a moderate disaster of subsurface water-logging; in general water-logging year, as well as in flood season that annual rainfall is normal, soil water-logging possibly arrives to moderate to severe from cotton seedling to boll-forming stage, so that cotton's nutrient growth and procreation growth are largely affected. Its developmental period could also be lagged due to soil moisture excess for many days and cotton yield therefore would be affected adversely.

Keywords: Cotton, duration of soil moisture excess, index of soil moisture excess, winter wheat

INTRODUCTION

Four-Lake Watershed (FLW) of Hubei Province, a first class tributary of the Yangtze River, located at the middle reach of the Yangtze River, it gets so name because of the four bigger lakes within the watershed that are Chang-hu, San-hu, Egret and Hong-hu lakes. The FLW is composed of a series of interfluve, it is the lowest place in Jiang-han plain, a typical area with a great deal of low-lying land, a region vulnerable to water-logging because of low topography and poor drainage, therefore an effective management of soil moisture is important for agricultural production. During a growth stage of crop, in case that soil moisture is excessive and exceeds a certain time, subsurface water-logging is inevitable for dryland crops and results in negative influences to the crops' growth and decline in the output and quality (Cannell *et al*., 1980; Kanwar *et al*., 1988; Musgrave, 1994; Zhu *et al*., 2003; Qin *et al*., 2013). For many years a lot of research on water-logging have been done, in which researchers have paid attention to groundwater depth and its dynamic change, precipitation and crop's response to waterlogged stress (Evans *et al*., 1991; Yan *et al*., 1991; Qiao, 1994; MWR, 2000; Zhu *et al*., 2008), etc. In fact, the situation of soil moisture impact on dryland crops directly and an influence of groundwater table on them is indirect. This study try to evaluate suitability of soil moisture for winter wheat and cotton based on analysis of long-term observation data, the objective is to guide the local agricultural production, reduce the loss of the crops' output.

MATERIALS AND METHODS

Twenty five years (1981 to 2005) of observational data with respect to precipitation and soil moisture were observed by Jingzhou Agricultural Meteorologic Trial Station of Hubei Province (AMTS), the rest data were gained from authors' investigation or relevant experiments. The AMTS is located at 112°09′E and 30°21′N, with surface elevation of 33.7-34.0 above mean sea level; the groundwater depth is 1.5-2.0 m in winter and 0.3-0.8 m in rainy season; generally, sampling of soil was done once per 5-8 days, using drying method to determine soil moisture. Crop growth stage was recorded according to variation of the crop agronomic properties.

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Table 1: Optimum soil moisture for winter wheat and cotton at various growth stages

Winter wheat		Cotton	
Development stage	Relative humidity/%	Development stage	Relative humidity/%
Seedling-turning green	70-75	Sowing-seedling	70-80
Turning green-jointing	60-70	Seedling	55-70
Jointing-booting	70-80	Budding	60-70
Filling-maturity	70-75	Blossoming and boll-forming	70-80
		Boll opening	55-70

Soil moisture indices and empirical criteria: A normal growth of crop needs suitable moisture which overabundance or insufficiency will affect crop development. Commonly, relative humidity of the soil is expressed as a percentage of soil moisture accounting for field moisture capacity, which optimum for winter wheat and cotton are listed in Table 1 (NAU *et al*., 1991; Zhang *et al*., 1994). When relative humidity of the soil is more than an allowable maximum in a growth period of crop it is called soil moisture excess, the severity of subsurface water-logging disaster in crop growth stage can be expressed as duration of soil moisture excess (T_h, day) and index of soil moisture excess (I_h). Duration of soil moisture excess refers to number of days that relative humidity of soil continuously exceeds an allowable maximum in a certain stage of crop. Index of soil moisture excess is analyzed according to average moisture of the topsoil, it is defined as a ratio that duration of soil moisture excess in a certain growth stage of crop is divided by a time length (T, day) corresponding to that stage, expressed as formula (1):

$$I_h = \frac{T_h}{T} \tag{1}$$

In light of author’s accumulation in relevant research, Table 2 gave an empirical criterion that describes a degree of subsurface water-logging. Reference Table 2, a degree of crop encountering subsurface water-logging can be estimated. In a growth stage or several stages or whole growth period of crop, if accumulated time (day) of soil moisture excess arrives to a certain extent corresponding to that in Table 2, the severity of subsurface water-logging should be lowered down a grade.

Calculation of drought/flood index: Ramdas (1950) defined a drought or flood with reference to the variation of southwest monsoon rainfall, according to Ramdas13, drought occurs when the actual southwest monsoon rainfall is less than the normal by twice the mean deviation or more and flood occurs when the actual southwest monsoon rainfall exceeds the normal by twice the mean deviation or more. Based upon the definition of drought and flood which was given by Shi and Su (1984) and Zhang (1999), drought/flood index (*DFI*) is calculated by formula (2):

Table 2: Indices of soil moisture excess and reference standard of subsurface water-logging

Severity	Mild	Moderate	Severe	Utmost
T_h (R_h≥90%) /d	6-14	15-20	21-25	>25
T_h (R_h≥100%) /d	3-7	8-15	16-20	>20
I_h (R_h≥90%)	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0

R_h-relative humidity of the soil within 0-30 cm, %

$$DFI = \frac{R_i - R_A}{\sigma_R} \tag{2}$$

where,

R_i = Precipitation at the i-th year, mm
R_A = Yearly precipitation, mm
σ_R = Standard deviation of rainfall during reference period

Here, in the light of criteria for the classification of drought and flood recommended by China's meteorological department: $DFI \le -2$ represents severe drought occurrence, $-2 < DFI \le -1$ illustrates drought, $-1 < DFI < 1$ demonstrates normal, $1 \le DFI < 2$ expresses flood or water-logging, and $DFI \ge 2$ indicates severe flood or water-logging.

Numerical statement and analysis of datum: Based on field moisture capacity, transform soil mass moisture observed in wheat field and cotton field into relative humidity, then according to developmental stage of crop to count the accumulated number of days that relative humidity of the soil exceeds a certain value, namely stress days of soil moisture excess unsuitable for crop in the stage.

Through statistically analyzing long-term precipitation data to obtain annual mean rainfall and standard deviation of rainfall, after that using formula (2) computes *DFI*. Then according to annual calculated result of *DFI* select typical hydrological year and analyze their soil moistures. In this study the representative years selected are 1984 (a general drought year, *DFI* = -1.4), 2004 (a normal year, *DFI* = -0.15), 2002 (general water-logging, *DFI* =1.4).

RESULTS AND DISCUSSION

Average annual soil moisture in various developmental stage of crop: Table 3 gave average annual soil moisture in different stage of winter wheat

Table 3: Annual average of indices of soil moisture unsuitable for crops

		T_h /d		I_h	
Crop	Developmental stage	$R_h \geq 90\%$	$R_h \geq 100\%$	$R_h \geq 90\%$	$R_h \geq 100\%$
Winter wheat	Jointing-booting	18.80	4.16	0.32	0.09
	Filling-maturity	13.40	2.72	0.33	0.06
Cotton	Seedling	16.68	3.40	0.35	0.09
	Budding	7.16	2.92	0.31	0.12
	Blossoming and boll-forming	13.36	3.28	0.23	0.06
	Boll opening	8.00	0.00	0.19	0.00

Table 4: Indices of soil moisture excess for winter wheat

		T_h /d		I_h	
Representative years	Developmental stage	$R_h \geq 90\%$	$R_h \geq 100\%$	$R_h \geq 90\%$	$R_h \geq 100\%$
1984	Jointing-booting	4	0	0.09	0.00
	Filling-maturity	0	0	0.00	0.00
2004	Jointing-booting	0	0	0.00	0.00
	Fillingp-maturity	0	0	0.00	0.00
2002	Jointing-booting	34	34	1.00	1.00
	Filling-maturity	46	46	1.00	1.00

Table 5: Indices of soil moisture excess for cotton

		T_h /d		I_h	
Representative years	Growth stage	$R_h \geq 90\%$	$R_h \geq 100\%$	$R_h \geq 90\%$	$R_h \geq 100\%$
1984	Seedling	0	0	0.00	0.00
	Budding	0	0	0.00	0.00
	Flowering and boll	0	0	0.00	0.00
	Boll opening	0	0	0.00	0.00
2004	Seedling	0	0	0.00	0.00
	Budding	16	0	0.76	0.00
	Flowering and boll	39	27	0.65	0.45
	Boll opening	7	0	0.37	0.00
2002	Seedling	21	17	0.51	0.41
	Budding	18	9	0.95	0.47
	Flowering and boll	38	36	0.72	0.68
	Boll opening	2	0	0.13	0.00

and cotton, compared relevant index of soil moisture excess in Table 3 with that in Table 2 from yearly average of soil moisture as can be seen, winter wheat in spring and cotton from seedling to blossoming and boll-forming stage usually encounter a mild subsurface water-logging, however cotton in boll-opening period seldom suffer from subsurface water-logging.

Suitability of soil moisture in typical year: Table 4 gave indices of soil moisture excess for winter wheat in three typical years, compared with corresponding that in Table 2, as can be seen, in general drought year and normal year a phenomena of soil moisture excess didn't exist for winter wheat in spring, namely no subsurface water-logging befell in the season; in general water-logging year, because it was rainy in spring the disaster of subsurface water-logging was extremely severe in wheat field, kernel weight of wheat was only 35.2 g, less than that in normal year 9-12 g and the yield was only 57.2% of normal levels.

Table 5 gave indices of soil moisture excess for cotton in various developmental stages in three typical years, by comparing the relevant indices in Table 5 and corresponding that in Table 2, as can be seen, there was no soil moisture excess in general drought year and cotton didn't suffer from subsurface water-logging, in normal year except moderate disaster of subsurface water-logging occurred in blossoming and boll-forming stage, the rest of developmental stages without subsurface water-logging; in general waterlogged year as well as in flood season of the normal year, the subsurface water-logging from cotton seedling stage to blossoming and boll-forming stage possibly reached medium to severe degree, it had an adverse impact on both vegetative growth and reproductive growth, even if a breed of cotton is tolerance to wet or resistance to water-logging, such as hybrid cotton Xiang-3, its growth season also apparently lagged due to a long-term influence of soil moisture excess on cotton plants and the yield of cotton therefore was affected adversely.

Owing to uneven distribution of rainfall in different season, a severe water-logging still possibly occurs in such a year that rainfall is normal, such as the year of 2004, in light of total precipitation it belongs to a normal year, but at the border zone between Jingzhou City and Qianjiang City in Hubei Province the precipitation achieved 840.8 mm during July to August, it was the second largest rainfall in summer in recent 50 years and the seasonal indices of drought/flood arrived to 2.30. Due to excessive rainfall the soil moisture was in overabundance for many days, this resulted in a severe water-logging in cotton field, a field investigation on 2 November 2004 showed that mortality of hybrid cotton Xiang-3 arrived to 28.67%, the ratio of boll dehiscence was merely 11.65% correspondingly the green boll accounting for 88.35% of total bolls.

CONCLUSION

Through analysis of a long series of observational data monitored by AMTS, indices of soil moisture excess for winter wheat and cotton were given. According to our results, some cognitions can be gained, which are summarized as following:

- From yearly average soil moisture in different developmental stage of crop, winter wheat in spring and cotton from seedling to boll stage usually encounter mild subsurface water-logging, generally water-logging seldom occurs in boll-opening period of cotton in the FLW.
- In light of typical years' analysis, no subsurface water-logging befall in general drought year; in normal year soil moisture excess doesn't exist for winter wheat and for cotton occurs in blossoming and boll-forming stage, which often leads to a moderate disaster of subsurface water-logging; in general water-logging year as well as in flood season which annual rainfall is normal, water-logging possibly arrives to moderate to severe from cotton seedling to boll stage, as a result cotton's nutrient growth and procreation growth are largely affected, its developmental period could also be lagged due to soil moisture excess and cotton yield therefore is affected adversely.
- Two indices, duration of soil moisture excess and index of soil moisture excess, can reflect the degree of subsurface water-logging. For those regions with many years of observational data, index of soil moisture excess and the corresponding methods can be used to analyze a potential harm caused by subsurface water-logging in different hydrological years, which has an important referential value for adjustment of planting structure of farm crops, reasonable arrangement of agricultural production.

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