Comparison of Precipitation from Different Meteorological Stations: A Case Study

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Abstract: Precipitation (P) can affect the growth, yield and quality of tobacco. This study compares P from the field automatic meteorological station (FMS) and national meteorological station (NMS) which are installed in different sites in Guiyang County, Chenzhou City of south Hunan Province on different time scales (whole year, tobacco-growing season and different tobacco-growing stages). The results show that P, P differences (ΔP), and day numbers of P difference (ΔP < 0 mm, = 0 mm, and > 0 mm) between FMS and NMS are different at different sites and different time scales. The range of ΔP between FMS and NMS are from 20.4 to 339.1 mm with the absolute error from 4.6% to 48.4%, and day number is 0 - 133 d for ΔP < 0 mm, 7 - 191 d for ΔP = 0 mm and 8 - 158 d for ΔP > 0 mm; In most cases the quadratic regression model could describe well the correlation in P between NMS and FMS on different time scales, but the accuracy of the regression model varies with different sites and different time scales. Therefore, it is necessary to determine climate zones firstly for a tobacco-planting region and then FMS should be installed for each zone to obtain the real zonal P data for meeting the requirements of fine meteorological services and revealing more accurately the relationship between climate and the growth, yield and quality of tobacco.

1 INTRODUCTION

Many studies in China have shown that precipitation (P) can directly affect the growth, yield and quality of tobacco (Xu and Wang, 2016; Liu, 2017 and 2020; Xu et al., 2019; Ji et al., 2021). Usually 0.8 - 1 kg of water is needed to produce 1 kg of tobacco leaves, and the suitable precipitation is 500 - 600 mm in the whole tobacco-growing season, among of which, 100 - 120 mm, 230 - 280 mm and 150 -180 mm in the rooting, flourishing and maturing stages of tobacco, respectively (Liu, 2017).

P is dependent on the spatial location and can be influenced by many factors, such as latitude, longitude, altitude, vegetation and so on. But in China there is usually only one national meteorological station (NMS) in a county and in most cases, it is not in the tobacco-planting region, thus, P of NMS can't reflect the real P of a tobacco-planting region, P predicted by the model based on the data of NMS may lead to the mis-decision and result in the adverse effects for the planting of high-quality tobacco.

In recent years the field automatic meteorological stations (FMS) have been installed in some tobacco-growing regions in China (Li et al., 2015a and 2015b; Liu, 2020; Shi and Liu, 2016), and have supported the determination of transplanting time of tobacco (Li et al., 2019) and the effects of climate parameters on quality formation of tobacco (Zha et al., 2014; Gao, 2021). However, usually the data of P have to be used from the nearest NMS for a tobacco-planting region without NMS, and also P data of multi years (for example, 20 years or more) from NMS nearest the tobacco-planting region have to be used to establish the predicting model of P because many FMS have not been setup for a long time in China. However, some studies found there are differences in the data of climate parameters (for examples, temperature, relative humidity and atmospheric pressure) between NMS and FMS even in the same small region (Chen et al., 2018 and 2019; Yu et al., 2021), however, no comparison so far is reported between P between FMS and NMS.

Chenzhou City, as the most typical region of Nanling Hill Ecological Zone of tobacco with the

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aroma style of burnt-pure sweet in China (Luo et al., 2019), is the largest tobacco-planting region in Hunan province, accounting for about 1/3 (2.67×10^4 hm^2) of the total tobacco-planting area in Hunan (Luo et al., 2017). Some studies were conducted on P in tobacco-growing regions in Chenzhou and showed that, according to the suitable values of P for the high-quality tobacco, P was unfavorable in rooting stage but suitable in flourishing and maturing stages of tobacco-growing (Rong, 2013), excessive P in early growing stage was a main factor inducing the occurrence of unfavorable "high temperature forced early-maturity" (Kuang, 2009), P changed irregularly on the scales of year, tobacco-growing season, and in the rooting and flourishing stages of tobacco-growing (Kong et al., 2020). However, the climatic data used in the above studies are either from NMS (Chen et al. 2015; Rong, 2013; Kuang, 2009; Kong et al., 2020) or from FMS (Gu *et al*, 2020; Wang, 2017), so far there is no report on P comparison between FMS and NMS, and the differences in P from different meteorological stations possibly can lead to the misjudgments about the relationship between P and tobacco. So here we propose the following two hypotheses: 1) P data recorded in the national metrological station (NMS) in a county (usually there is only one NMS in a county in China) is different from that recorded in the metrological station (FMS) installed in the tobacco-planting region, which is mainly due to the difference in the spatial sites, also to the differences in terrain, land use type and so on, so P data of NMS can't be directly used to establish the model for predicting P in the tobacco-planting region, for it would lead to mis-decisions and the adverse effects on tobacco planting. 2) there is a certain correlation and comparability between precipitation data of NMS and FMS, this correlation is dependent on the location and time, and could be used to modify the model based on P data of NMS in order to improve further the prediction accuracy of P in the tobacco-planting region. We hope that the results of our study can prove further that FMS should be installed in tobacco-planting region in revealing more accurately the relationship between P and tobacco-planting, and meet the requirements of fine meteorological services in the tobacco-planting region.

2 MATERIALS AND METHODS

2.1 Information of Study Region

Chenzhou City is located in the southeast of Hunan province of south-central China, between 112˚13' to 114˚14' in east longitude and 24˚53' to 26˚50' in north latitude with a total area of 1.94×10^4 km^2, which belongs to subtropical monsoon humid climate with annual mean temperature of 15.4-18.3°C, cumulative sunshine hours of 1510.3-1764.3 hrs, precipitation of 1320.3-1654.7 mm and frost-free season of 235-296 d (Rong, 2013). The altitude of Chenzhou City ranges from 70 to 2061 m, and the landform is complex with mountains and hills accounting for about 3/4 of the total area. The main soil types are red soil, yellow-red soil and paddy soil (Hunan Agriculture Department, 1989), and the total area of cultivated land is 30.96×10^4 hm^2 with the areas of 25.94×10^4 hm^2 of paddy fields (Chenzhou Municipal Bureau of Statistic, 2018). Tobacco is mainly cultivated in paddy fields under the rotation of tobacco and late rice.

2.2 Sources, Processing and Analysis of Climate Parameters

The original daily cumulative P are from the NMS in Guiyang County (GY, No. 57973) and from FMS (Temperature and Humidity Recorder 179-TH, Beijing Dingxuan Shengshi Technology Co., Ltd.) in Fangyuan Town (FY) and Aoquan Town (AQ), two important tobacco-planting regions in GY installed in October 2019.

Three-time scales are used in our study, which include the whole year (from January 1 to December 31), tobacco-growing season (from March 10 to July 20) and different tobacco-growing stages (the rooting stage from March 10 to April 20; the flourishing stage from April 21 to May 31, and maturing stage from June 1 to July 20).

Microsoft Excel 2016 and IBM Statistics SPSS 22.0 software are used for data processing and analysis. The abnormal data are eliminated according to the mothed of mean ± 3×S.D. The significant difference and correlation are indicated by $p<0.05$ or $p<0.01$.

3 RESULTS

3.1 Comparison of P between FMS and NMS on Different Time Scales

The statistical information of P of FMS and NMS at different time scales is presented in Table 1 From Table 1 it can be seen that P, absolute error (AE) and relative error (RE) of P between FMS and NMS are different at different time scales, the range of P difference between FMS and NMS are from 20.4 to

339.1 mm with the absolute error from 4.6% to 48.4%. At the scale of year, in 2020, P of FY and AQ was 154.6 mm (10.5%) and 149.8 mm (10.2%) higher than GY, respectively. However, in 2021, P of FY and AQ was 339.1 mm (20.7%) and 142.4 mm (8.4%) lower than GY, respectively. At the scale of tobacco-growing season, in 2020, P of FY and AQ was 75.7 mm (10.0%) and 35.2 mm (4.6%) higher than GY, respectively. However, in 2021, P of FY was 67.5 mm (8.4%) lower than GY, while P of AQ was 139.6 mm (17.4%) higher than GY. At rooting and flourishing stages in 2020 and 2021, P of FY and AQ was 117.1 mm (30.2%), 61.0 mm (15.7%) and 20.4 mm (11.8%), 76.4 mm (44.3%) higher than GY in 2020; 26.0 mm (14.0%), 49.1 mm (26.5%) and 18.9 mm (4.6%), 16.7 mm(4.1%) higher than GY in 2021; while at maturing stage, in 2020, P of FY and AQ was 67.4 mm (36.7%) and 74.9 mm (40.8) lower than GY, respectively; However, in 2021, P of FY was 106.8 mm (48.4%) lower than GY, while P of AQ was 46.5 mm (21.1%) higher than GY. The statistical information of day numbers of P difference ($\Delta P < 0$ mm, $= 0$ mm, and > 0 mm) between FMS and NMS at different time scales is presented in Table 2. From Table 2 it can be seen that the day numbers of ΔP are different at different time scales, day number is 0-133 d for $\Delta P < 0$ mm, 7-191 d for $\Delta P = 0$ mm, 8-158 d for $\Delta P > 0$ mm. At the scale of year, there are 27.0%-36.3%, 40.7%-49.3% and 23.0% of days in 2020-2021 in FY with P lower than, equal to and higher than in GY, respectively; 4.4%-29.8%, 41.3%-52.3% and 28.9%-43.3% of days in 2020-2021 in AQ with P lower than, equal to and higher than in GY, respectively. At the scale of tobacco-growing season, there are 27.8%-33.1%, 39.1%-42.9% and 27.8%-29.3% of days in 2020-2021 in FY with P lower than, equal to and higher than in GY, respectively; 0-33.1%, 42.1%-43.6 % and 24.8%-56.4% of days in 2020-2021 in AQ with P lower than, equal to and higher than in GY, respectively. In rooting stage, there are 40.5%, 21.4%-40.5% and 19.0%-38.1% of days in 2020-2021 in FY with P lower than, equal to and higher than in GY, respectively; 0-57.1%, 16.7%-50.0% and 26.2%-50.0 % of days in 2020-2021 in AQ with P lower than, equal to and higher than in GY, respectively. In flourishing stage, there are 0-31.7%, 29.3%-39.0% and 29.3%-70.7% of days in 2020-2021 in FY with P lower than, equal to and higher than in GY, respectively; 0-31.7%, 26.8%-36.6% and 31.7%-73.2 % of days in 2020-2021 in AQ with P lower than, equal to and higher than in GY, respectively. In maturing stage, there are 14.0%-18.0%, 56.0%-64.0% and 22.0%-26.0% of days in 2020-2021 in FY with P lower than, equal to and higher than in GY, respectively; 0-14.0%, 54.0%-60.0% and 26.00%-46.0% of days in 2020-2021 in AQ with P lower than, equal to and higher than in GY, respectively.

Table 1: Comparison of P on different time scales.

Scale	Year	GY	FY			AQ		
		P (mm)	P (mm)	AE (mm)	RE (%)	P (mm)	AE (mm)	RE (%)
Whole year	2020 (n=366)	1466.8	1621.4	154.6	10.5	1616.6	149.8	10.2
	2021 (n=365)	1636.0	1296.9	-339.1	-20.7	1493.6	-142.4	-8.7
Tobacco-growing season	2020 (n=133)	757.3	833.0	75.7	10.0	792.5	35.2	4.6
	2021 (n=133)	803.6	736.1	-67.5	-8.4	943.2	139.6	17.4
Rooting stage	2020 (n=42)	388.2	505.3	117.1	30.2	449.2	61.0	15.7
	2021 (n=42)	172.4	192.8	20.4	11.8	248.8	76.4	44.3
Flourishing stage	2020 (n=41)	185.4	211.4	26.0	14.0	234.5	49.1	26.5
	2021 (n=41)	410.7	429.6	18.9	4.6	427.4	16.7	4.1
Maturing stage	2020 (n=50)	183.7	116.3	-67.4	-36.7	108.8	-74.9	-40.8
	2021 (n=50)	220.5	113.7	-106.8	-48.4	267.0	46.5	21.1

Notes: AE = FY or AQ - GY, RE(%) = (FY or AQ - GY)×100/GY.

Table 2: Day numbers of different P values at different time scales.

Time scale	Site	Period		ΔP (°C)						Total (days)
				< 0		0		> 0		
				Day	%	Day	%	Day	%	
Year	FY	2020		133	36.3	149	40.7	84	23.0	366
		2021		101	27.7	180	49.3	84	23.0	365
	AQ	2020		109	29.8	151	41.3	106	28.9	366
		2021		16	4.4	191	52.3	158	43.3	365
Tobacco season	FY	2020		37	27.8	57	42.9	39	29.3	133
		2021		44	33.1	52	39.1	37	27.8	133
	AQ	2020		44	33.1	56	42.1	33	24.8	133
		2021		0	0	58	43.6	75	56.4	133
Growing stage	FY	2020	Rooting	17	40.5	9	21.4	16	38.1	42
			Flourishing	13	31.7	16	39.0	12	29.3	41
			Maturing	7	14.0	32	64.0	11	22.0	50
		2021	Rooting	17	40.5	17	40.5	8	19.0	42
			Flourishing	0	0	12	29.3	29	70.7	41
			Maturing	9	18.0	28	56.0	13	26.0	50
	AQ	2020	Rooting	24	57.1	7	16.7	11	26.2	42
			Flourishing	13	31.7	15	36.6	13	31.7	41
			Maturing	7	14.0	30	60.0	13	26.0	50
		2021	Rooting	0	0	21	50.0	21	50.0	42
			Flourishing	0	0	11	26.8	30	73.2	41
			Maturing	0	0	27	54.0	23	46.0	50

Notes: P = GY-FY or GY-AQ.

3.2 Regression Models of P between NMS and FMS at Different Time Scales

SPSS software were used to decide the optimal regression model of P between FMS and NMS based on the comparison of the accuracies of all kinds of models listed in SPSS, although there are obvious differences in P between FMS and NS, Table 3 shows in most cases the quadratic regression model could describe well the correlation in P between FMS and NMS on different time scales except in FY at the scale of tobacco-growing season, in rooting stage in 2020 and maturing stage in 2021, and in flourishing stage in AQ in 2020. It also can be seen from Table 3 that, p are 0.000 except in AQ in flourishing and maturing stages in 2020 (p=0.081 and 0.016) and in maturing stage in 2021 (p=0.190). R^2 is 0.298-0.733 with a mean of 0.511 in FY and AQ at the scale of year, 0.323-0.732 with a mean of 0.518 in FY and AQ at the scale of tobacco-growing season, and 0.068-0.819 with a mean of 0.542 at the scales of the different tobacco-growing stages.

4 DISCUSSION

It is well-known that P are different in different sites even in small space, our study also not only found the differences in P between FMS and NMS, but also found the difference in P between FMS in FY and in AQ. Generally, P is increased with the decreases of latitude and the increase of altitude and vegetation coverage, but it actually is still very difficult or impossible to give a clear quantitative explanation for the difference in P in the three sites of our study even there are the information available of longitude, latitude, altitude, topography, land use type and vegetation coverage of the three sites listed in Table 4. For examples, the latitude from north to south is 25°55′36″ for FMS in AQ, 25°44′58″ for NMS in GY, and 25°40′49″ for FMS in FY, the altitude from high to low is GY (329,1 m), FY (320.4 m) and AQ (250.0 m), which are not consistent with P, which from high to low is FY (1621.4 mm), AQ (1616.6 mm) and GY (1466,8 mm) in 2020, GY (1636.1 mm), AQ (1493,6 mm) and FY (1296.9 mm).

Table 3: Regression models of P between NMS and FMS at different time scales.

Time scale	Site	Year	Regression model	R^2	p
Year	FY	2020	$y = -0.004x^2 + 1.125x + 0.296$	0.733	0.000
		2021	$y = -0.003x^2 + 0.787x + 0.440$	0.593	0.000
	AQ	2020	$y = -0.016x^2 + 1.314x + 0.732$	0.419	0.000
		2021	$y = 0.003\ x^2 + 0.213x - 0.440$	0.298	0.000
Tobacco season	FY	2020	$y = 1.039x + 0.345$	0.732	0.000
		2021	$y = -0.004\ x^2 + 0.929x + 0.774$	0.641	0.000
	AQ	2020	$y = -0.012\ x^2 + 1.094x + 1.639$	0.323	0.000
		2021	$y = -0.011\ x^2 + 1.180x + 2.145$	0.375	0.000
Rooting stage	FY	2020	$y = 1.201x + 0.931$	0.788	0.000
		2021	$y = 0.007x^2 + 0.648x + 1.378$	0.748	0.000
	AQ	2020	$y = -0.020x^2 + 1.719x + 0.694$	0.708	0.000
		2021	$y = -0.016x^2 + 1.566x + 0.828$	0.568	0.000
Flourishing stage	FY	2020	$y = 0.024x^2 + 1.668x – 0.147$	0.753	0.000
		2021	$y = -0.009x^2 + 1.328x + 0.560$	0.819	0.000
	AQ	2020	$y = 0.451x + 3.679$	0.076	0.081
		2021	$y = -0.011x^2 + 1.353x + 1.254$	0.743	0.000
Maturing stage	FY	2020	$y = 0.009x^2 + 0.280x + 0.434$	0.775	0.000
		2021	$y = 0.410x + 0.465$	0.302	0.000
	AQ	2020	$y = -0.019x^2 + 0.817x + 0.987$	0.162	0.016
		2021	$y = -0.011x^2 + 0.785x + 3.465$	0.068	0.190

Notes: in regression model, y and x are the data of climate parameters from the field and national stations, respectively.

Table 4: Information of FMS and NMS in Guiyang County (GY) of Chenzhou City.

Meteorological Station	Site	Longitude	Latitude	Altitude (m)	Terrain	Land use	Period of P data
FMS	FY	112°40′0″	25°40′49″	320.4	plain	Farmland	2020.1.1-2021.12.31
FMS	AQ	112°34′36″	25°55′36″	250.0	Plain	Farmland	2020.1.1-2021.12.31
NMS (No. 57973)	GY	112°43'29"	25°44'58"	329.1	hill	Forest	2020.1.1-2021.12.31

Notes: FY and AQ are the main tobacco-growing towns of GY.

Meanwhile, we think the stability and reliability of P data of NMS data is better than that of FMS, which is based on the facts that we have found that in other tobacco-planting regions, FMS occasionally does not work well, thus affect the accurate acquisition of P data. Anyhow, we believe that as long as FMS is under normal operation in the tobacco field, the obtained precipitation data are reliable and acceptable.

Compared with the suitable P at tobacco-growing season and at different tobacco-growing stages, according to Table 5, the suitability of P for tobacco-planting are similar (all are excessive) in GY, FY and AQ in tobacco-growing season and in rooting stage in 2020 and 2021, in flourishing stage in 2021, in the maturing stage (all are insufficient) in 2021, while it is different in flourishing stage in 2020 and maturing stage in 2021, in which P is insufficient in GY and FY, but suitable in AQ in 2020, while P is excessive in GY and AQ and insufficient in FY in 2021, which means that sometimes the differences in P from different meteorological stations possibly can lead to the misjudgments about the relationship between P and tobacco, it is necessary to obtain the real data of P for a specific site when analyze the relation between P and the growth, yield and quality of tobacco.

The previous studies on comparison between FMS and NMS mainly focused on the differences in temperature, relative humidity and atmospheric pressure (Chen et al., 2018 and 2019, Yu et al., 2021), so far, there is no report on P difference between FMS and NMS, which may be due to more complex influential factors (mainly include site, terrain, vegetation, hydrological condition, and human activities) or high spatial variation of P. Our study compares (Table 6) the accuracy in predicting P at FY and AQ stations in the same period by using the models of whole year, tobacco-growing season and different tobacco-growing stages between FMS and NMS. It can be seen from Table 6 that tobacco growing season model is more accurate than whole year model in predicting P in tobacco-growing season and in maturing stage in FY and AQ in 2020 and 2021. But the optimal model is different in predicting P in rooting and flourishing stages, for examples, in rooting stage, tobacco-growing season model is more accurate for FY in 2020 and AQ in 2021, while rooting model is more accurate for FY in 2021 and AQ in 2020; In flourishing stage, tobacco-growing season model is more accurate for FY in 2020 and 2021, while flourishing model is more accurate for AQ in 2020 and 2021, which mean the site and time scale must be considered when predicting P with regression model between NMS and FMS.

Table 5: Suitability assessment of P at different time scales.

Time scale	Suitable P (mm)*	Year	GY		FY		AQ	
			P (mm)	Suitable or no	P (mm)	Suitable or no	P (mm)	Suitable or no
Tobacco season	500-600	2020	757.3	excessive	833.0	excessive	792.5	excessive
		2021	803.6	excessive	736.1	excessive	943.2	excessive
Rooting stage	100-120	2020	388.2	excessive	505.3	excessive	449.2	excessive
		2021	172.4	excessive	192.8	excessive	248.8	excessive
Flourishing stage	230-280	2020	185.4	insufficient	211.4	insufficient	234.5	suitable
		2021	410.7	excessive	429.6	excessive	427.4	excessive
Maturing stage	150-180	2020	183.7	insufficient	116.3	insufficient	108.8	insufficient
		2021	220.5	excessive	113.7	insufficient	267.0	excessive

Notes: Data of suitable P are from Liu 2017.

Table 6: Accuracy of regression models of P between NMS and FMS at different time scales.

Time scale	Model	FY				AQ			
		2020		2021		2020		2021	
		ME	RSME	ME	RSME	ME	RSME	ME	RSME
Tobacco-growing season	Year	0.18	1.94	-1.23	4.15	-0.62	6.93	-5.28	10.54
	Season	0.58	0.79	-0.27	2.89	-0.22	6.73	2.43	2.61
Rooting stage	Year	-0.31	3.37	0.78	2.47	1.61	7.18	4.53	9.48
	Season	0.81	1.12	0.11	1.47	1.63	7.41	2.45	2.52
	Rooting	3.49	5.17	0.34	1.45	1.25	5.29	1.14	2.53
Flourishing stage	Year	0.42	0.52	2.84	6.15	1.10	10.01	-7.71	12.26
	Season	0.54	0.67	-1.38	4.23	-0.54	9.22	2.78	2.81
	Flourishing	6.42	15.92	11.24	21.16	0.53	7.67	1.51	2.65
Maturing stage	Year	0.41	0.50	-0.38	3.12	0.6	1.47	-3.9	9.83
	Season	0.44	0.50	0.30	2.39	1.23	2.19	2.13	2.45
	Maturing	-0.83	3.10	-0.88	5.09	-0.38	5.02	-0.37	12.84

5 CONCLUSION

Our study shows that there are obvious differences in P between FMS and NMS in different locations and at different time scales even in the same tobacco-planting county. Although P is significantly correlated between NMS and FMS in most cases, and the regression models could be used in predicting P from the data of NMS for a tobacco-growing region without FMS, however, the accuracy of the regression model varies with different sites and different time scales, therefore, it is necessary to determine climate zones firstly for a tobacco-planting region, and then FMS should be installed for each zone to obtain the real P data of the zone to meet the requirements of fine meteorological services and to reveal more accurately the relationship between climate and tobacco in the tobacco-growing region.

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