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11-Year Rainfall and Maize Yield Variation (2003-2013) in Four Northern Districts of Malawi

Naohiro Matsui[1]

[1] Environment department, The General Environmental Technos Co., Ltd., Osaka, Japan

Correspondence: Naohiro Matsui, Environment Department, The General Environmental Technos Co., Ltd., 1-3-5 Azuchimachi, Chuo-ku, Osaka 541-0052, Japan. Tel: 81-6-6263-7314. E-mail: matui_naohiro@kanso.co.jp

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Abstract

Rainfall in the maize cropping season (Oct-Apr) in the four northern districts of Malawi was examined in terms of seasonal fluctuation and spatial distribution, and data spanning 11 years were analyzed. Rainfall fluctuations in the 11-year period differed considerably among the four districts and the Extension Planning Areas (EPAs) showed high coefficients of variance (CVs) (16.9-93.7). The equation with the three-month rainfall (October, February, and April), i.e., Maize yield (kg/ha) in SH = 2.29 + 0.0042 × Oct rainfall – 0.0009 × Feb rainfall + 0.00045 × Apr rainfall ($r^2 = 0.41$), better explained maize yield in the 2013/14 season than the equation with total rainfall in the cropping season. Rainfall accounted for more than 41% of the total variation in maize yields of smallholder farmers (SHs). Rainfall in April was the most critical factor influencing maize and other crop yields. After the Farm Input Subsidy Programme (FISP) was implemented in 2005/06, maize yield became more dependent on rainfall. CV was higher in maize than in groundnut and sweet potato, indicating that maize is susceptible to rainfall fluctuations, and groundnut and sweet potato should be incorporated in farming as a countermeasure against unpredictable rainfall.

Keywords: rainfall variation, maize yield, coefficient of variance (CV), smallholder farmer

1. Introduction

Increasing inorganic fertilizer prices, decreasing farm size, and declining soil fertility are the major constraints of current agricultural practice in Malawi. Malawi has been experiencing high seasonal variability in maize yield in the last few decades. A 43% national food deficit was recorded in 2005 and a 53% surplus, in 2007 (Denning et al., 2009). A major factor affecting maize yield is chemical fertilizer application. To this end, the government of Malawi has been offering chemical fertilizer subsidies to farmers since 2006. For one bag of fertilizer (50 kg) sold at the market price of around 15,000 MKT (60 US dollars as of Oct 2014), farmers could purchase it at 500 MKT (= 1 US dollar).

Maize is the most important staple food crop in Malawi (JAICAF, 2008) and in Africa (Byerlee & Heisey, 1996). Almost all maize crops are grown without irrigation during the single rainy season that starts in October and ends in April; thus, the crops are subject to rainfall variability that can be particularly damaging when short dry spells occur during the critical flowering and early grain filling stages (Famine Early Warning Systems Network, 2007). Several studies have indicated that the availability of adequate rainfall is by far the greatest limiting factor in maize production in sub-Saharan Africa (CIMMYT, 1988; Diallo et al., 1989; Ammani et al., 2012). As drought during the flowering and grain filling period may lead to 40-90% crop loss (Grant et al., 1989; NeSmith & Ritchie, 1992; Menkir & Akintunde, 2001), total crop failure due to drought is experienced once every ten years in semi-arid sub-Saharan Africa (Ngigi, 2003), and 80% of the cultivated maize crops have reduced yield due to drought stress (Bolonos & Edmeades, 1993).

Global warming is expected to intensify drought problem in Africa (Edmeades, 2008) and rising temperatures will be associated with greater rainfall variability and increase the frequency of severe weather events such as droughts and floods (Boko et al., 2007). Rainfed agriculture accounts for more than 95% of farmed land in sub-Saharan Africa, meaning that the effects of drought are likely to be more damaging than in developed nations where irrigation is more prevalent (Rockstrom & Falkenmarkac, 2000). In order to attain sustainable food security under uncertain climatic conditions, it is necessary to examine how much rainfall contributes to maize yield at the regional level. This will lead to better farm management in order to sustain or improve maize yield.

In this study, we examined rainfall patterns in the northern region of Malawi during the last 11 years from 2003 through 2013 and determined rainfall influence on maize yields of smallholder farmers (SHs). We also clarified which months of the cropping season (October to April) are important for enhancing the yields of different maize varieties. Furthermore, other common crops, such as cassava, sweet potato, finger millet, and groundnuts, were examined in terms of adaptability to rainfall fluctuations.

2. Materials and Methods

2.1 Description of Study Sites

The study sites were located in the four northern districts of Malawi, namely, Mzimba North (N), Mzimba South (S), Nkhatabay, and Rumphi (Figure 1). Those districts were composed of Extension Planning Areas (EPAs). The EPAs had two lower sublevels, Section and Block. The number of EPAs was 7 in Mzimba N, 12 in Mzimba S, 8 in Nkhatabay, and 6 in Rumphi as of 2013.

The mean annual rainfall over a 22-year period between 1989 and 2011 was 1,129 mm in Mzimba N, 702 mm in Mzimba S, 612 mm in Rumphi, and 1,610 mm in Nkhatabay. Rainfall patterns of the four districts were almost identical (Figure 2): high rainfall from November to April and low rainfall from May to October. Nkhatabay had very high rainfall in March and April relative to the other districts.

2.2 Information Collection and Statistical Analysis

Rainfall and maize yield data of the northern districts for the period between 2003 and 2013 were obtained from the Planning Department of Mzuzu Agricultural Development Division (ADD). Regarding rainfall data, descriptive statistics, including the mean, maximum, and minimum values and the coefficient of variance (CV), were calculated. The Planning Department collects maize and other crop yield data every year according to the methodology devised by the Ministry of Agriculture and Food Security (2008). 25% of the Blocks were randomly selected from each Section. In each selected Block, all households were listed and 20% of them, namely, more than 15 households, were identified. The overall sampling number represented approximately 5% of all agricultural households.

Although hybrid and composite maize crops are characterized by their remarkable seed yields, seed prices are high and fertilizers are required. Therefore, they are planted only when the government introduces a support scheme. The unit yields of the hybrids are higher than those of traditional varieties, but so is the cost incurred. For this reason, a production area would register a temporary increase when chemical fertilizer and improved seeds are provided free of charge. Generally, farmers in remote areas grow traditional varieties (local), whereas farmers living near the capital cultivate hybrid and/or composite varieties.

Statistical analysis was conducted using the software JMP 8.0.2 version for Windows (SAS Inc., 2009). Besides general statistical analysis, multiple regression analysis was carried out for rainfall and maize yield to understand which month(s) affected maize yield in a particular year.

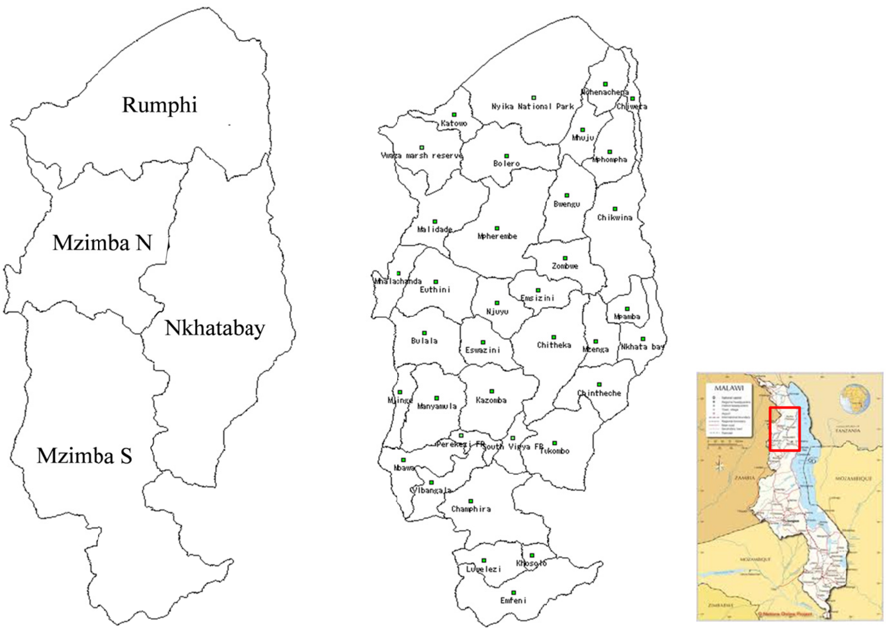

Figure 1. Location of study site composed of four districts (Mzimba N, Mzimba S, Nkhatabay, and Rumphi) subdivided into 33 Extension Planning Areas (EPAs)

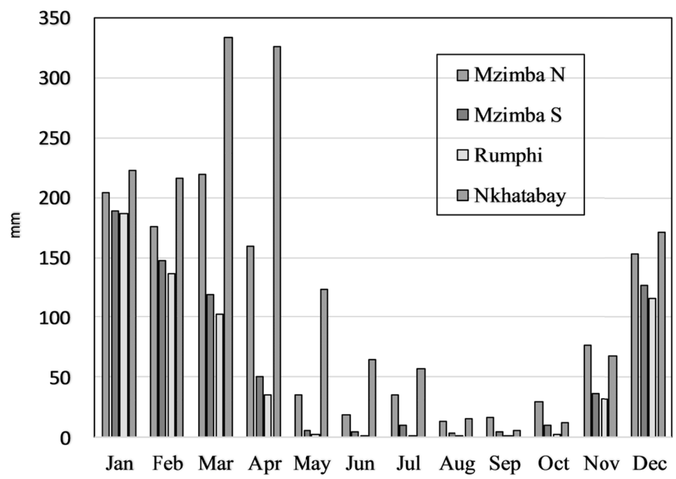

Figure 2. Mean monthly rainfall (mm) for the period between 1989 and 2012 in four northern districts of Malawi

3. Results and Discussion

3.1 Seasonal Rainfall Fluctuations

High rainfall was observed in Nkhatabay, which was approximately 1.5-fold of that in Mzimba Mzimba N and Mzimba S showed high CVs, indicating that rainfall was unpredictable and varied yearly. Rainfall was also quite variable among EPAs in the same district, as shown by the high CVs of 18.2 to 93.7 (Mzimba N), 16.8 to 65.6 (Mzimba S), and 18.5 to 61.1 (Nkhatabay) (Table 1).

Table 1. Statistical values for rainfall during the period between 2003 and 2013 in the four districts and their EPAs

District	EPA	N	Mean	Min	Max	Stdv	CV
Mzimba N	Bwengu	11	895	394	1659	423	49.2
	Zombwe	10	1144	472	4062	1072	93.7
	Emsizini	10	922	324	2031	538	58.4
	Mpherembe	10	892	610	2120	452	50.7
	Malidade	10	824	609	1041	150	18.2
	Mbalachanda	10	820	414	1412	289	35.2
	Euthini	10	860	591	1515	268	31.2
	Mean		903			456	48.1
Mzimba S	Njuyu	10	727	533	1002	150	20.7
	Bulala	10	892	313	1957	449	50.3
	Eswazini	10	687	502	932	170	24.8
	Manyamula	10	997	583	1329	211	21.2
	Mjinge	10	884	518	1475	370	41.9
	Kazomba	10	756	492	1252	214	28.3
	Mbawa	10	1010	498	2790	652	64.6
	Vibangalala	10	681	520	1023	148	21.8
	Champhira	10	928	545	1929	384	41.3
	Emfeni	10	1008	573	2837	661	65.6
	Luwerezi	10	728	508	899	122	16.8
	Khosolo	10	1071	801	1856	299	27.9
	Mean		864			319	35.4
Nkhatabay	Tukombo	10	1392	785	2646	539	38.7
	Chintheche	10	1215	749	2035	387	31.8
	Limphasa	10	1236	765	1909	385	31.1
	Nkhata Bay	10	1441	742	3546	880	61.1
	Mpamba	10	1164	670	1754	309	26.5
	Mzenga	9	952	365	1280	288	30.2
	Chikwina	10	1272	847	1657	236	18.5
	Chitheka	10	1157	789	1842	311	26.9
	Mean		1229			417	33.1
Rumphi	Katowo	10	985	523	1252	213	21.7
	Bolero	10	635	464	913	144	22.6
	Mhuju	10	641	474	1087	167	26.1
	Mchenachena	10	1126	853	1431	190	16.9
	Chiweta	10	1405	691	1940	381	27.1
	Mphompha	10	864	646	1374	202	23.4
	Mean		984			245	24.4

Note. EPA: Extension Planning Area; N: Number of data; Min: Minimum; Max: Maximum; Stdv: Standard deviation; CV: Coefficient of Variance.

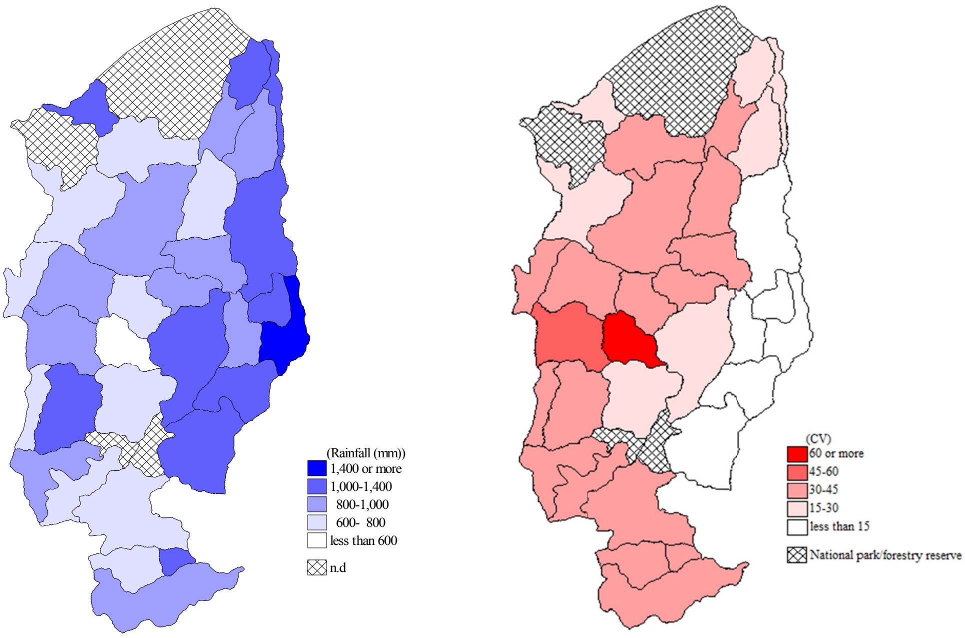

Figure 3. Means (left) and coefficients of variance of rainfall (right) during the cropping season for the period between 2003 and 2013

Mean rainfall in the cropping season was quite variable among the EPAs (Figure 3): the range was from less than 600 mm to 1,400 mm or more. High rainfall exceeding 1,000 mm was observed mainly in Nkhatabay, whereas the other districts showed low rainfall. Mzimba N, Mzimba S, and Rumphi had high CVs, indicating that yearly rainfall variation was quite high. Typical maize crop requires approximately 500 mm/season to mature (FAO, 2012) and rainfall below 500 mm is not sufficient to meet maize crop water requirements. Some EPAs in Mzimba N and Mzimba S had less than 500 mm rainfall for the period between 2003 and 2013, which led to a severe decline of maize yield. As an example of rainfall fluctuations, Emsizini EPA located in Mzimba N recorded less than 500 mm rainfall in the three seasons (2005/06, 2009/10, 2010/11) for the period between 2004/05 and 2013/14, whereas this EPA recorded over 2,000 mm rainfall in 2013/14.

3.2 Maize Production

Maize yields of SHs varied among the districts. Nkhatabay and Rumphi demonstrated high and constant maize yields for the period between 2004/05 and 2013/14, as shown by the low CVs (15 or less). In contrast, Mzimba N and Mzimba S exhibited low and variable maize yields as reflected by the high CVs (Table 2).

Mean yields for the period between 2003 and 2014 were 2,755, 2,066, and 1,056 kg/ha for hybrid, composite, and local maize, respectively (Table 3). Hybrid and composite showed more than twice the yield of local maize. The unit yield of cassava (kg/ha) was 10 times higher than that of maize, and that of sweet potato was 6 times higher. In the same period, the mean maize yield of SHs was 2,175 kg/ha, similar to that of hybrid maize, indicating that the majority of SHs had used the hybrid variety more than the local variety.

Until 2006, maize yield had been around 1,000 kg/ha, but was increased by twofold in 2006 and beyond (Table 4). This was because the government of Malawi introduced the Farm Input Subsidy Programme (FISP) in 2005/06. FISP focuses on maize production subsidy; the full package was composed of 5-10 kg of seed and 100 kg of fertilizer. After FISP was implemented, the yields of hybrid and composite maize crops almost doubled. In contrast, the yields of local maize did not change in 2006/07 and beyond (Table 4), showing that FISP provided seeds of hybrid and/or composite maize but not the local variety to SHs.

Annual maize yields differed among the four districts (Figure 4). The impact of FISP was relevant in Mzimba N and Mzimba S, but not in Nkhatabay and Rumphi, possibly because FISP did not distribute the subsidy coupons equally (Dorward et al., 2008; Holden & Lunduka, 2010; Ricker-Gilbert et al., 2011).

Table 2. Means and coefficients of variance of maize yields (kg/ha) of SHs for the period between 2003 and 2013

Maize yield in SH	N	Mean	Stdev	CV
Mzimba N	73	1,837	588	32.0
Mzimba S	99	1,778	610	34.3
Nkhatabay	72	2,707	405	15.0
Rumphi	48	2,709	458	16.9

Note. SH: Smallholder; N: Number of data; Stdev: standard deviation; CV: Coefficient of variance.

Table 3. Means and coefficients of variance of maize and other crop yields (kg/ha) for the period between 2003 and 2013

	N	Mean	Stdev	CV
Maize				
Smallholder	292	2,175	696	32.0
✓ Hybrid maize	292	2,755	757	27.5
✓ Composite maize	292	2,066	579	28.0
✓ Local maize	292	1,056	349	33.1
Cassava	292	21,985	5,108	23.2
Sweet potato	292	14,577	3,244	22.3
Groundnuts	287	607	145	23.9
Tobacco	262	1,097	224	20.5

Note. N: Number of data; Stdev: Standard deviation; CV: Coefficient of Variance.

Table 4. Changes in maize yield (kg/ha) for the 10-year period between 2004/2005 and 2013/2014

	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14
SH	1253.3^{a}	1322.7^{a}	2423.3^{b}	$1849.1^{b,c}$	$2646^{c,d}$	$2795.2^{d,e}$	$2571.6^{d,e}$	$2407.7^{d,e,f}$	$2090.8^{e,f}$	2336.4^{f}
Hybrid	1787.1^{a}	1891.4^{a}	3116.1^{b}	$2297.2^{b,c}$	$3429.3^{c,e}$	$3317.9^{e,f}$	3210.0^{f}	$3011.5^{f,d}$	$2562.4^{f,d}$	2809.0^{d}
Composite	1339.1^{a}	1370.7^{a}	2549.6^{b}	1878.3^{b}	2388.1^{c}	$2443.1^{c,d}$	$2375.4^{d,e}$	2176.8^{e}	$1900.1^{d,e}$	2140.8^{e}
Local	801.5^{a}	869.0^{a}	1231.9^{a}	966.0^{a}	1251.9^{a}	1308.8^{b}	1231.8^{b}	1152.0^{b}	882.2^{b}	906.8^{b}

Note. SH: Smallholder, different letters indicate statistically significant difference at the level of 0.05.

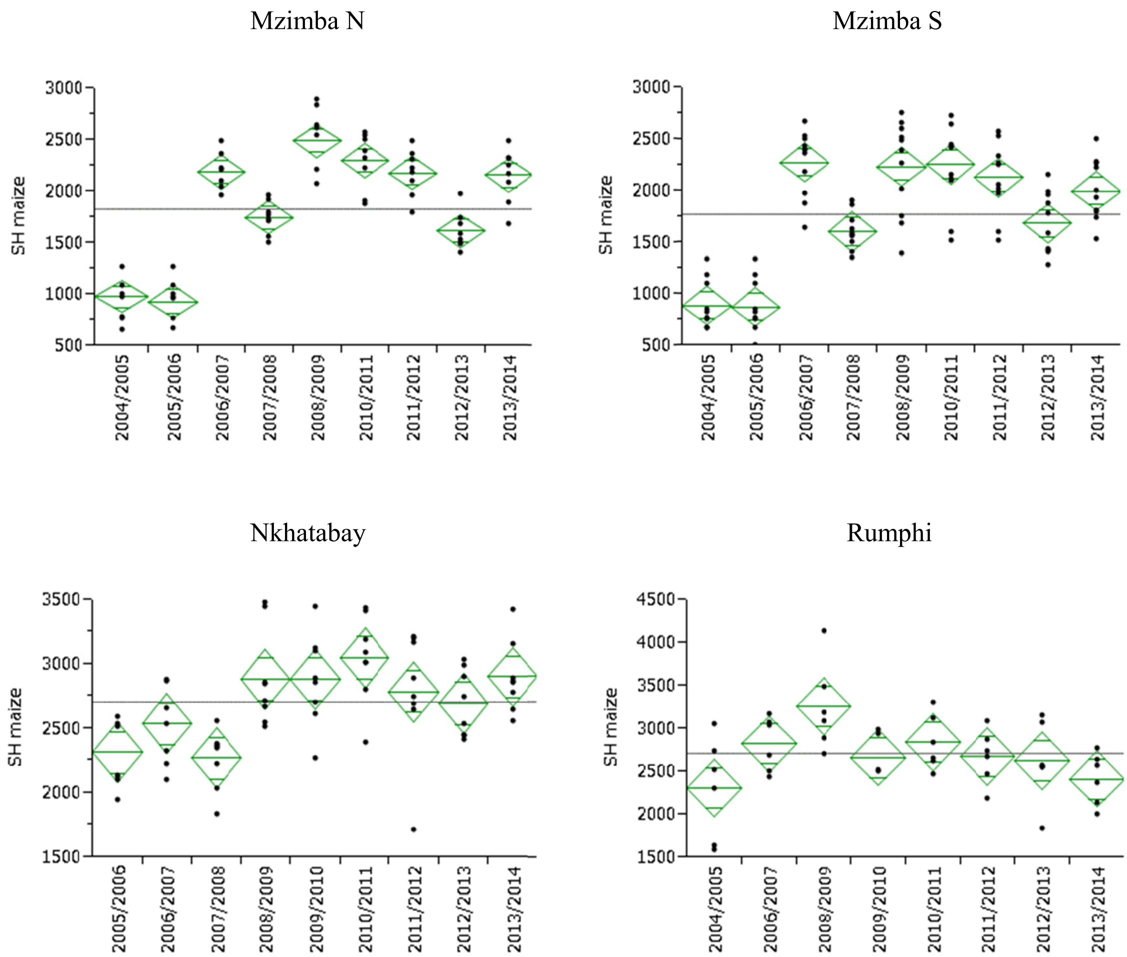

Figure 4. Changes in maize yield (kg/ha) of SHs in the four districts (Diamond box indicates 95% confidence interval and centerline indicates mean value.)

3.3 Effects of Rainfall on Maize Yields

Maize yield of SHs was likely influenced by rainfall, as exemplified by the high maize yields in places where rainfall was high in the 2013/14 cropping season (Figure 5). For maize yield in 2013/14, regression analysis was conducted and the following equation was obtained:

$$\text{2013/14 maize yield (kg/ha)} = 1.95 + 0.00023 \times \text{Total rainfall from Oct to Apr} \quad (r^2 = 0.14) \tag{1}$$

Furthermore, multiple regression analysis was conducted using rainfall data for October, February, and April, and the following equation was obtained:

$$\text{2013/14 maize yield (kg/ha)} = 2.29 + 0.0042 \times \text{Oct rainfall} - 0.0009 \times \text{Feb rainfall} + 0.00045 \times \text{Apr rainfall} \quad (r^2 = 0.41) \tag{2}$$

The equation with the three-month rainfall (October, February, and April) better explained the maize yield in 2013/14 than the equation with total rainfall in the cropping season. Rainfall accounted for more than 41% of the total variation of maize yield in 2013/14. Other factors, such as soil properties and farm management, would account for the remaining 59% of variance.

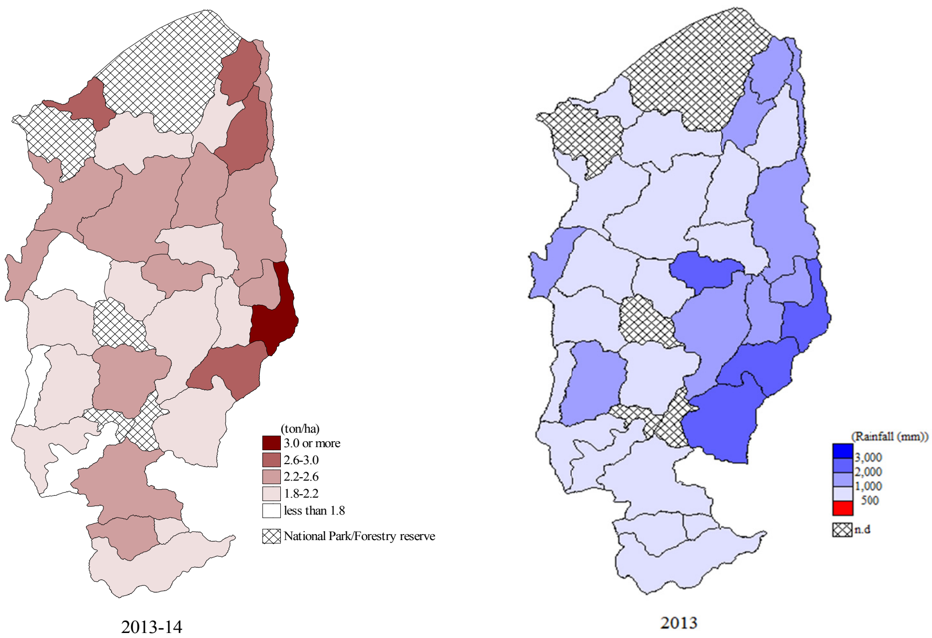

Figure 5. Maize yields (kg/ha) in 2013/14 and rainfall during the cropping season from Oct 2013 through Apr 2014

Table 5. Coefficient of determination (R^2) between maize yield of SH and rainfall (mm) for the years 2004/05 to 2013/14 (data for 2005/06 are not available), and month(s) that showed statistically significant difference in maize yield in the multivariate regression model

	Predictor variable	[1)]Regression coefficient	P value of coefficient	R^2	P value of model
2004/05	Intercept	1120.0	0.0020	0.30	0.6422
2005/06					
2006/07	Intercept	2847.3	< .0001	0.06	0.9761
2007/08	Intercept	1546.3	< .0001	0.65	0.0021
2008/09	Intercept	3280.6	< .0001	0.48	0.0137
	Apr rainfall	2.43	0.0440		
2009/10	Intercept	2986.8	0.0054	0.36	0.8594
2010/11	Intercept	3153.4	< .0001	0.50	0.0085
	Nov rainfall	-4.43	0.0258		
2011/12	Intercept	2403.3	< .0001	0.34	0.1350
2012/13	Intercept	2052.5	< .0001	0.62	0.0007
	Jan rainfall	-2.07	0.0490		
	Feb rainfall	-3.38	0.0165		
2013/14	Intercept	2219.7	< .0001	0.56	0.0831

Note. [1)] This is partial regression coefficient in multiple regression analysis.

The effect of rainfall on maize yields of SHs was changed during the period between 2004/05 and 2013/14 (Table 5). After the implementation of FISP in 2005/06, maize yields of SHs became more dependent on rainfall, as indicated by the increase in the coefficient of determination (R^2). In 2006, the year FISP was implemented, the correlation of rainfall with maize yield was not significant (R^2 = 0.06); however, it became greater in the later years (2012/13; R^2 = 0.58, 2013/14; R^2 = 0.59). The months affecting maize yield varied depending on the year.

Nevertheless, November, January, February and April were likely to be more critical than the other months.

Hybrid and composite were more strongly influenced by rainfall than the local variety. Multiple regression analysis showed that R^2 was lower for the local variety than for hybrid and composite (Table 6). Maize yields of all types were correlated with rainfall in April and the regression coefficient was the highest in hybrid. February was another month affecting maize yield in composite. The negative regression coefficients for December rainfall in hybrid and composite and January rainfall in local variety indicated that rainfall in those months adversely affected maize yield.

Table 6. Coefficient of determination (R^2) between maize yield (kg/ha) of hybrid, composite, local and rainfall (2003/04-2013/14), derived from multivariate regression model

	Predictor variable	[1)]Regression coefficient	P value of coefficient	[2)]R^2	P value of model
Hybrid	Intercept	2908.8	< .0001	0.23	< .0001
	Dec rainfall	-1.01	< .0001		
	Apr rainfall	0.97	0.0008		
Composite	Intercept	2061.6	< .0001	0.22	< .0001
	Dec rainfall	-0.78	< .0001		
	Feb rainfall	0.69	0.0441		
	Apr rainfall	0.70	0.0016		
Local	Intercept	1070.9	< .0001	0.17	< .0001
	Jan rainfall	-0.39	0.0047		
	Apr rainfall	0.68	< .0001		

Note. [1)] This is partial regression coefficient in multiple regression analysis; [2)] Statistics degree of freedom adjusted coefficient of determination.

Table 7. Coefficients of variance (CVs) of maize and other crops produced during the period between 2003 and 2013 in the four districts

District	SH maize	Maize variety			Finger millet	Cassava	Sweet Potato	G/nuts	Soybean	Tobacco
		Hybrid	Composite	Local						
Mzimba N	26.4	27.2	30.6	23.3	18.1	9.3	12.7	17.4	25.1	24.1
Mzimba S	27.1	28.3	29.8	24.3	21.9	12.2	14.8	22.1	19.7	12.1
Nkhatabay	12.5	12.5	11.7	17.8	31.4	12.9	12.0	22.1	65.1	36.7
Rumphi	12.2	19.1	20.6	25.2	9.6	14.4	12.2	17.4	23.2	13.5

Note. SH: smallholder, G/nuts: groundnuts.

The CVs of crops produced during the period between 2003 and 2013 varied according to crop type and differed among the districts (Table 7). Maize production of SH varied more in Mzimba N and Mzimba S than in Nkhatabay and Rumphi. The CVs of all maize types were low in Nkhatabay, possibly because of the stable and high rainfall, whereas the low rainfall in Mzimba N and Mzimba S could be one reason for the high variability of maize yield. Multiple regression analysis of maize production of SH for the period between 2003 and 2013 gave the following equation:

$$SH = 2378.6 - 0.87 \times \text{Dec rainfall} - 0.32 \times \text{Jan rainfall} + 1.44 \times \text{Apr rainfall} \quad (r^2 = 0.31) \tag{3}$$

April rainfall was the determinant month, as was shown in the Equation (2). As April rainfall is lower in Mzimba N and Mzimba S than in the other districts (Figure 2), the risk of lower yield would be higher in those districts. Other crops, such as cassava and sweet potato, showed low CVs. In Mzimba N, CV of cassava was 9.3 and in Mzimba S, CV of finger millet was 9.6, which meant that those crops are resistant to rainfall fluctuations and thus would be promising as a countermeasure against drought. CV of soybean in Nkhatabay was 65.1, and such a high CV could be due to fungal infection as a result of high rainfall.

Table 8. Coefficient of determination (R^2) between crops and rainfall (2003/04 –2013/14), derived from multivariate regression model

	Predictor variable	[1)]Regression coefficient	P value of coefficient	[2)]R^2	P value of model
Finger millet	Intercept	676.4	< .0001	0.28	< .0001
	Dec rainfall	-0.19	0.0007		
	Apr rainfall	0.64	< .0001		
Cassava	Intercept	19951.5	< .0001	0.27	< .0001
	Jan rainfall	-5.53	0.0057		
	Apr rainfall	13.7	< .0001		
Sweet potato	Intercept	13530.1	< .0001	0.29	< .0001
	Nov rainfall	6.91	0.0322		
	Dec rainfall	-2.63	0.0010		
	Jan rainfall	-2.60	0.0332		
	Feb rainfall	4.51	0.0232		
	Apr rainfall	8.55	< .0001		
Groundnuts	Intercept	616.0	< .0001	0.22	< .0001
	Nov rainfall	0.41	0.0059		
	Dec rainfall	-0.14	< .0001		
	Jan rainfall	-0.13	0.0176		
	Apr rainfall	0.32	< .0001		
Soybean	Intercept	881.0	< .0001	0.15	< .0001
	Dec rainfall	-0.20	< .0001		
	Apr rainfall	-0.23	0.0137		
Tobacco	Intercept	1071.7	< .0001	0.10	< .0001
	Apr rainfall	0.33	0.0037		

Note. [1)] This is partial regression coefficient in multiple regression analysis; [2)] Statistics degree of freedom adjusted coefficient of determination.

The coefficient of determination (R^2) was measured for the other crops (Table 8). All crops except sweet potato showed low coefficients of determination. Sweet potato requires high rainfall as shown by its high regression coefficient (14.6). Finger millet, cassava, tobacco also require relatively high rainfall in April.

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