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National yield reference for sugarcane management: Thailand case study

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Abstract

In this study, a tool is proposed to assist small-scale sugarcane farmers in Thailand in justifying their field management practices. The tool is a master chart derived from the relationship between annual average rainfall and national sugarcane yield and consists of three curves: the mean, the upper bound, and the lower bound. The chart allows farmers to assess the condition of their fields by plotting the coordinates of annual rainfall and yield to observe the position in relation to the three curves. The ratio of actual yield to the upper bound yield also helps in the justification process. This proposed method offers an alternative to the traditional yield gap technique, which is difficult to obtain, unreliable, and not standardized for the whole country. The relationship equation of the annual rainfall and detrended yield has been formulated from the hypothesis that their derivative follows an exponential decay. After obtaining the trend (mean), the upper and lower bounds can be derived for the 95th and 5th percentiles, respectively. The master chart, along with the yield-ratio concept, has been tested against three field observations and four field experiments.

Keywords: Innovative trend analysis, Small holding farmers, Yield master chart, Yield ratio

1. Introduction

Potential yield, the ceiling indicating the maximum achievable crop yield, is commonly used as a benchmark to quantify the degree of cropping improvement by comparing it with actual yield. The difference between actual yield and potential yield is the yield gap. The larger the gap, the greater the crop improvement required. Potential yield can be evaluated using model simulations and/or crop data evaluations [1]. Crop simulation models naturally involve uncertainty. For instance, Edreira et al. [2] found simulated potential yields to be lower than the corresponding actual yields. Data-based methods are not truly representative of target fields and take a considerable time to compile [3]. Due to the varying definitions and methods, potential yield is more of a concept rather than a quantity [4].

Extreme climate in Thailand is getting more intense and frequent, posing a serious problem for Thai farmers over the past few decades, the majority of whom are smallholders [5]. Since the small-scale farmers are themselves subject to food insecurity, helping them can add to the benefits of sustainable food security while raising their income [6]. Small-scale farmers in Thailand typically cultivate a variety of crops during the year, such as rice, maize, vegetables, cassava, and sugarcane.

In Thailand, sugarcane is an important industrial crop for sugar and biofuel factories. It is the country's third-highest crop revenue provider after rice and rubber [7]. Fifty-seven sugar mills located throughout the country need sugarcane as raw material to reach full capacity during the milling season. The Thai sugar industry requires three key stakeholders to work together: farmers, millers, and the government. Failure at the farm level negatively impacts sugar factories and reduces the country's revenue. From a small-holding farmer's perspective, their goal is to generate maximum profit by optimizing several income sources rather than maximizing a single-crop yield (e.g., sugarcane). Therefore, the potential yield value is not the appropriate benchmark for sugarcane farming performance. For Thailand's agricultural sector to mitigate extreme climate impacts and address economic volatility, Thai sugarcane farmers must be equipped with wise tactical (short-range) management in addition to strategic (long-range) management practices. Accordingly, the benchmark for yield reference should be straightforward and standardized for the whole country to enable all small farmers to use it with ease for tactical decisions. It must also be able to keep up with climate change [7].

Currently, potential yield is not standardized for the whole country but varies spatially and depends on many determinants, e.g., climate, soil, and land characteristics [1]. As a benchmark, this study looks for an alternative to overcome the effect of rainfall variability, which is standardized for the whole country. Each year, annual national rainfall and sugarcane yield are unique. Through statistical analysis, the relationship between the two may give a clue for benchmarking, in similarity to the work of Calviño and Sadras [8], who related soybean yield with seasonal rainfall. However, they limited their data to less than five years to avoid increments in yield trends. Longer data series, however, are preferable for smoothing out disruptions such as pests and diseases. Therefore, the detrending of time series data is required [9].

Since sugarcane in Thailand is essentially a one-year cycle crop from the beginning to the end of a year, its yield must be affected by the entire year's rainfall. Long-term historical data for national sugarcane yield and annual average rainfall are the key variables for initiating the new benchmark. It is necessary to observe the trends of both yield and rainfall and detrend them if required. This study intends to create a master chart based on the rainfall-yield relationship to assist sugarcane management, which can be easily used by farmers, millers, and extension officers.

The objectives of this study are, therefore, to (i) investigate the trends of annual average sugarcane yield and related rainfall and detrend them if required, (ii) formulate a set of suitable equations representing the relationships between annual rainfall and sugarcane yield and its range of dispersion, illustrated as a set of curves, and (iii) test and validate the derived equations and curves with the findings in the literature.

2. Materials and methods

2.1 Study area and data acquisition

Sugarcane cultivation areas in Thailand are concentrated around 57 sugar mills, extending from the lower northern to upper southern regions and from the western plain to the Mekong River in the East. Sugarcane farms cover a total area of 1.76 million hectares, representing 35.9% of the country's field crop area and 7.4% of its entire agricultural land [7]. Thailand has two climate zones—the upper main part and the southern peninsular [5]. Sugarcane cultivation occupies the country's main part, which is subject to the southwest monsoon from May to October and the northeast monsoon from November to March. The rainy season, between May and October, receives two sources of rain: the southwest monsoon and the Pacific tropical cyclone. The average annual rainfall from 1961 to 2021 is reported to be 1366.48 mm (S.D. 165.58 mm) with two peaks, the smaller one in June and the larger one in September. More than 90% of sugarcane cultivation in Thailand is rainfed. On average, its life cycle is one year, with the planting season being from October to March and harvesting taking place during November to April of the following year [7]. Sugarcane comprises four stages of growth: germination (one month), tillering and elongation (three months), grand growth (six months), and maturity (two months). This growth pattern matches well with the climatic pattern. The germination and ratoon sprouting period benefits from cool weather and plenty of soil moisture remaining from the preceding rainy season. A few rain events occur between February to April, helping tillering and elongation to develop. May to October is the period of greatest rainfall and grand growth, requiring the most water supply, while the rain becomes gradually weaker and the temperature cooler from November onward, matching with the maturity period of sucrose accumulation for which sugarcane needs dry and cool weather [7].

2.2 Annual rainfall and sugarcane yield of the main part of Thailand.

The annual, spatially averaged rainfall of the main part covering the sugarcane cultivation area was retrieved for this study from the gridded precipitation database of the Climatic Research Unit (CRU) for 1961 to 2021 [10]. The database was reasonably well matched with other precipitation databases and ground-based observation and has been used for crop yield analysis [9]. The annual rainfall time series fluctuated along the average of 1366.48 mm (Figure 1). To check the need for annual rainfall detrending, innovative trend analysis was chosen following the study of Caloiero [11].

The analysis was performed by separating the whole chronological dataset into two equal sub-datasets, each sorted in ascending order. The pairs of sorted sub-datasets were plotted with the first subset on the x-axis and the second on the y-axis. The scattered points were related to the 1:1 line, above the line indicating an ascending trend, below the line descending, and on or near the line indicating trendless [12]. Annual yields of sugarcane in Thailand from 1961 to 2021 were retrieved from Food and Agriculture Organization (FAO) [13]. The FAO national crop data is the most consistent source of information that dates back to the 1960s. The yield and rainfall are plotted as time series from 1961 to 2021 in Figure 1.

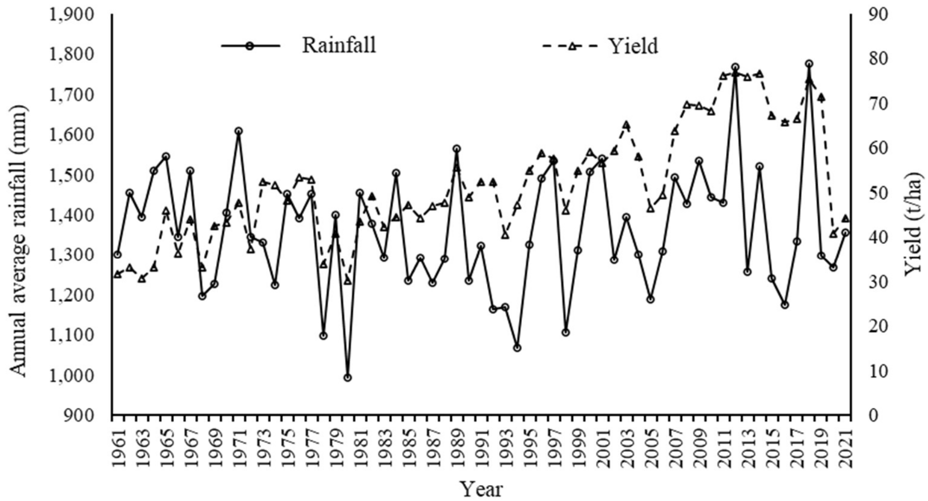

Figure 1 Time series of annual rainfall and corresponding sugarcane yield in Thailand.

2.3 Sugarcane production, yield, and harvested area, in Thailand.

Figure 1 shows the increase in yield trend due to improved varieties and advanced management practices. Its detrending was necessary to eliminate the effects of other variables besides annual rainfall [9]. Actual yield time series (y_t) has two components, mean or trend ($\bar{y}_t$) and anomaly (ε_t), that is $y_t = \bar{y}_t + \varepsilon_t$ for t=1, 2, 3,…, T, where y_t, $\bar{y}_t$, and ε_t are functions of time from 1 to T.

Three trend simulation models for nonlinear time series, namely cubic spline, polynomial regression, and moving average, were compared to select the one most suitable. A comparison procedure began by separating the anomaly (ε_t) from the increasing trend ($\bar{y}_t$). The anomaly set was then raised to an appropriate constant mean value ($\bar{Y}$) by adding $\bar{Y}$ to ε_t to obtain a counterfactual yield time series (y_t). These y_t's are hypothetical, emerging as if the advancement of technology had occurred since the beginning (1961). The empirical cumulative probability distribution (ecdf) of each y_t series was then plotted against its theoretical normal distribution. The best-matched pair gave the best simulation procedure. Weibull empirical distribution was used with an equation of $F_s = m/(n+1)$, with F_s being ecdf, and m the order of ascending data from 1 to n.

2.4 Equation of nonlinear relationship of yield and annual rainfall.

Water stress causes crop yield reduction. Rainfed crop yield increases with the amount of rainfall; however, the rate of increase diminishes as rainfall values rise. A few studies on the relationship between yield and rainfall at the critical growth stage show positive nonlinearity, with a steeper slope at lower rainfall becoming flatter at higher rainfall [1,8]. Since the sugarcane crop in Thailand is rainfed and has a one-year cycle on average from the beginning to the end of a year, the amount and distribution of annual rainfall are essential for its growth and yield. The relationship between sugarcane yield and annual rainfall shows a nonlinear feature with the derivative of yield with respect to annual rainfall, being exponential decay,

$$dy/dr = ke^{-cr} \tag{1}$$

where y = yield, r = annual rainfall, k = slope at zero r, and c = decay constant. Integrating Equation (1) with some manipulation gives,

$$y = a+b(1- e^{-cr}) \tag{2}$$

Equation (2) explains the relationship between crop yield and rainfall [1]. It can be used for country average sugarcane yield with annual average rainfall while a, b, and c are constants. Once the parameters are obtained for the average curve, the upper and lower bound curves can be determined using the 95% and 5% cumulative probability distribution, respectively.

3. Results and discussion

3.1 Time series of detrended yield and counterfactual yield

Figure 1 shows the detrended yield time series to eliminate the effects of advanced technologies. Three trend simulation models, i.e., cubic spline, polynomial regression, and five-year moving average, were used to determine counterfactual yield time series. A counterfactual series refers to a yield time series that fluctuates along the fixed mean of an average yield of five years (2014 to 2018) representing current technology. The ecdf of each counterfactual yield time series was determined and then fitted with a normally distributed cdf. Figure 2 shows polynomial regression as the best model. The Kolmogorov-Smirnov test results (Table 1) give polynomial regression as the most appropriate method with the highest p-value and lowest D statistic value at a significance value of 0.001. In this study, polynomial regression was therefore accepted for detrending the actual yield.

Table 1 Kolmogorov-Smirnov test results of yield with the three methods at significant value of 0.001.

Statistic	Cubic Spline	Polynomial regression	Moving average	Critical value
D	0.119	0.068	0.145	0.208
p-value	0.801	0.999	0.606	0.001

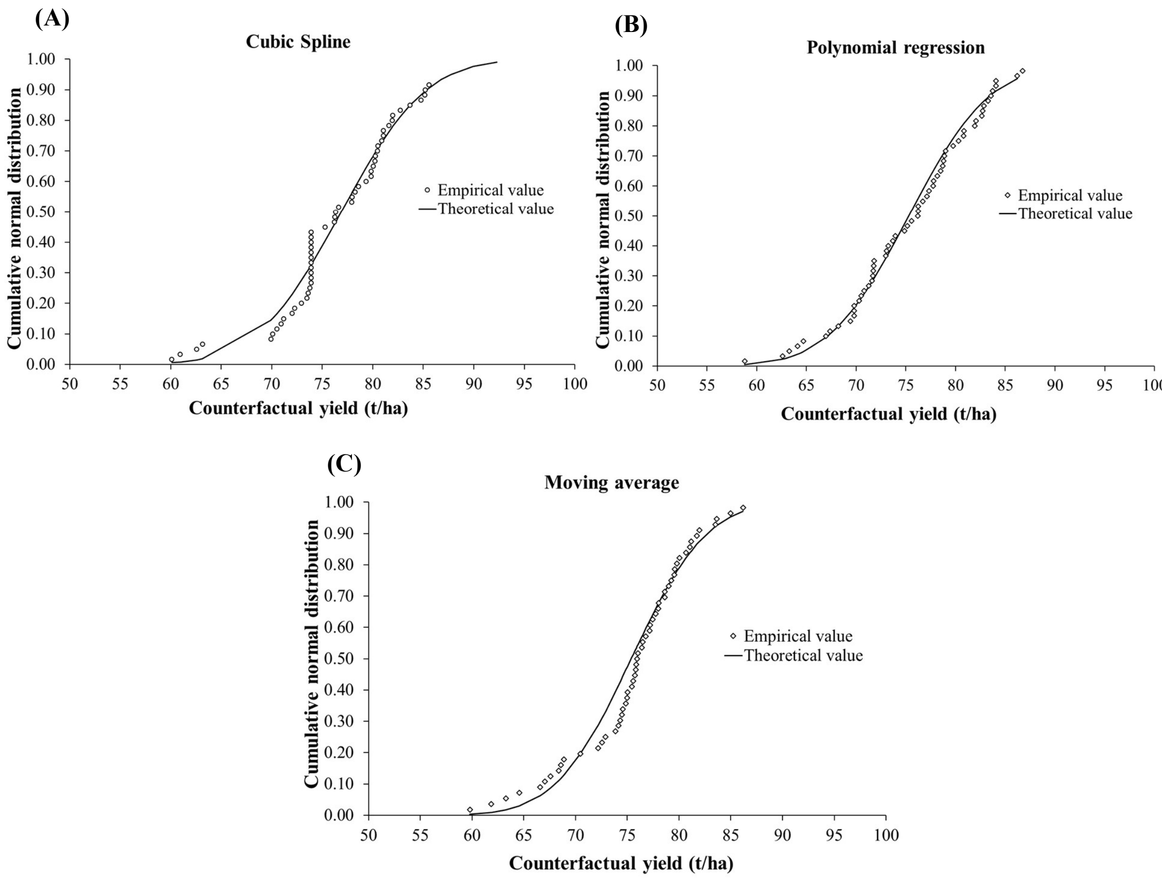

Figure 2 Normality comparison of counterfactual yields from methods of (A) cubic spline, (B) polynomial regression, and (C) five-year moving average.

3.2 Relationships of counterfactual yield and annual rainfall

Figure 1 presents the annual average rainfall series of Thailand from 1961 to 2021, analyzed using the innovative method of Sen [11,12] as explained in Section 2.2. Figure 3 shows the results of the analysis, demonstrating a trendless phenomenon except for three points at both ends, which show an increasing trend. Therefore, there was no need to detrend the annual rainfall time series prior to further investigation.

The values of annual average rainfall versus counterfactual sugarcane yields are plotted in Figure 4. Since the relationship is nonlinear, the Spearman's correlation could be used, revealing a value of 0.53. A moderate correlation value of 0.53 implies that annual rainfall is one of the main factors affecting yield. Other contributing factors include the management of soil and weeds, as well as pest and disease control practices [3]. The rainfall and yield relationship trend can be formulated according to Equation (2), $y = a+b(1- e^{-cr})$. For a given value of r, however, the yield is large for the crop with good management and vice versa. The upper and lower bound equations are also added using Equation (2) at the 95th and 5th percentiles, respectively (Table 2 and Figure 4).

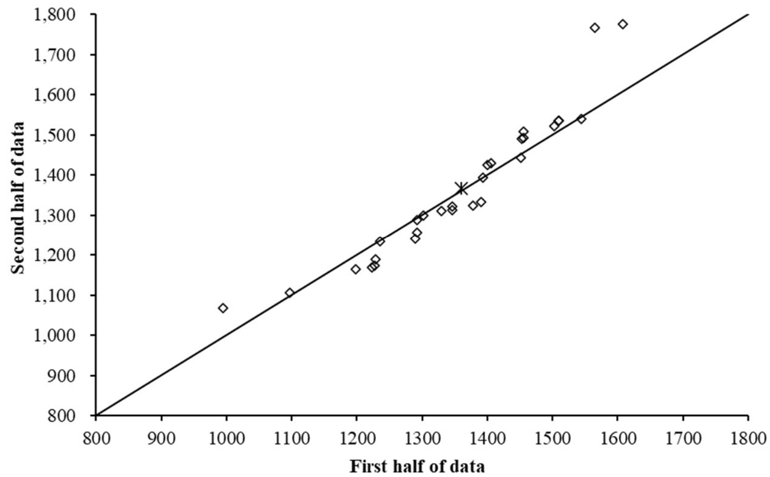

Figure 3 Innovative trend analysis of Thailand's annual rainfall with mean (*) and 1:1 line.

Table 2 Constant values of the mean, upper-, and lower-bound.

Curve	Constants		
	a	b	c
Mean	-14	121	0.00100
Upper bound	-13.5	130	0.00110
Lower bound	-18	110	0.00095

3.3 Yield references and implementations

A set of yield references comprises the mean as well as the upper and lower bound curves, as shown in Figure 4. The curves can be updated to keep up with climate change by adding new data annually. The master chart of yield references can be used by all three stakeholders, i.e., farmers, millers, and official extension services, to improve sugarcane cultivation in Thailand. The chart is easy to use, merely requiring the actual yield of known annual rainfall to be plotted on the master chart. The value is then located in one of the four portions: (1) below the lower bound, (2) between the lower bound and the mean, (3) between the mean and the upper bound, and (4) above the upper bound. The position of the actual yield on the chart tells the cultivated situation. Portion 1 indicates poor cultivation, and portion 4 is very good. Farmers can always learn from the change in yield related to annual conditions and then consult with the factory's experts and/or government extension services to improve their cultivation. The level of yield is indicated by the ratio of actual yield to the upper bound of the reference yield at the same annual rainfall value. When the ratio is higher than 1, the yield situation is located above the upper bound in portion 4. The higher the ratio, the better the yield. For example, if the yield is always far below the lower bound in portion 1 or has a very small yield-ratio value, the field is likely to be unsuitable for sugarcane. A few examples from real situations in the literature should make things clearer.

3.3.1 Examples of implementations

The following seven examples demonstrate the application of the yield reference chart (Figure 4): three from field observations and four from field experiments, as detailed in Table 3. The field observations took place in Khon Kaen (KFO), Chaiyaphum (CFO) [3], and Nakornsawan (NFO) [14] provinces. The field experiments were conducted in Borabue District (BFE), Muang District (MFE) [15], Phitsanulok (PFE) [16], and the Khon Kaen Field Crop Research Centre (KFE) [17]. It should be noted that field observation aims to explore the actual field performance and the field experiment to evaluate the effect of its treatment. The field observation yield is influenced by the field environment (climate, soil type, and topography) and typical yield determinants (cultivar, crop class, and management). The field experiment yield indicates the maximum or potential yield under specific treatment.

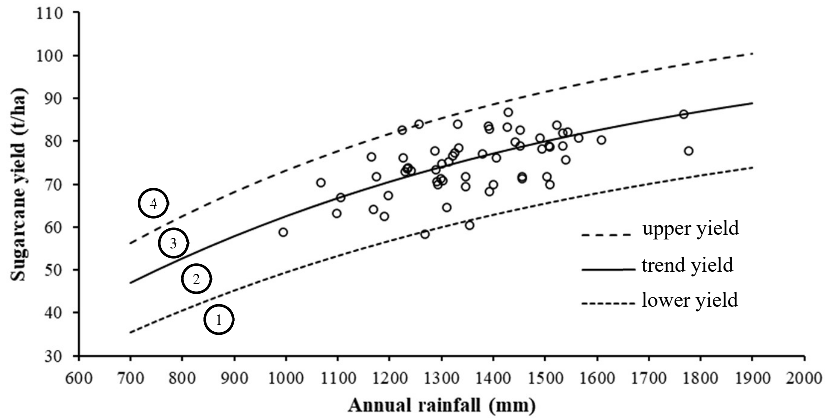

Figure 4 The relationship of annual rainfall and sugarcane yield with trend, upper, and lower bounds.

Table 3 Details of study sites

Site	Village/District	Province	Latitude	Longitude	Soil	Study type
KFO	Hin Kong	Khon Kaen	16°27.2'N	102°38.3'E	Sandy	Field observation
CFO	Gud Mak Heb	Chaiyaphum	16°22.6'N	102°07.7'E	Clayey	Field observation
NFO	Tak Fa	Nakornsawan	15°20.9'N	100°25.3'E	Clay loam	Field observation
BFE	Borabue	Mahasarkham	16°07.3'N	103°09.2'E	Sandy	Field experiment
MFE	Muang	Mahasarkham	16°11.6'N	102°12.7'E	Clayey	Field experiment
PFE	Bang Rakum	Phisnulok	16°38.3'N	100°09.0'E	Clayey	Field experiment
KFE	Muang	Khon Kaen	16°29.0'N	102°49.9'E	Sandy loam	Field experiment

3.3.2 Examples for field observations

The first field observation was conducted at Hin Kong village, Khon Kaen, during 2012 with planted crop, 1st+2nd ratoon, and 3rd+4th ratoon, of 50, 50, and 16 fields, respectively [3]. The second took place at Gud Mark Heb, Chaiyaphum, during 2014 with planted crops, 1st+2nd ratoon, and 3rd+4th ratoon, of 30, 36, and 12 fields, respectively [3]. The third observation at Tak Fa, Nakornsawan, involved a single field with planted crops in 2012 and the first ratoon in 2013 [14]. The results of these observations are shown in Table 4 and Figure 5.

Table 4 Results of the three field observations.

Year	Site	Type	Rainfall (mm)	Upper bound (t/ha)	Actual yield (t/ha)	Ratio
2012	KFO	Planted	1377.0	87.9	104.3	1.187
2012	KFO	Ratoon1&2	1377.0	87.9	103.2	1.174
2012	KFO	Ratoon3&4	1377.0	87.9	86.1	0.980
2014	CFO	Planted	794.0	62.2	106.7	1.715
2014	CFO	Ratoon1&2	794.0	62.2	86.1	1.384
2014	CFO	Ratoon3&4	794.0	62.2	65.2	1.048
2012	NFO	Planted	1201.93	81.85	72.19	0.882
2013	NFO	Ratoon1	1162.11	80.29	69.44	0.865

In the first observation case, KFO, the yield ratios of planted cane, ratoons 1 & 2, and ratoons 3 & 4 of the same year at Hin Kong village were compared with the ratios of 1.187, 1.174, and 0.980, respectively (Table 4). The ratio decrements from planted cane to ratoon 1 & 2 and ratoon 3 & 4 indicate that the yield of planted cane was always the highest and decreased with the degree of ratooning, which aligned with the results of other studies [18]. The ratio reduction between planted crops and ratoon 1 & 2 was 0.013 or 1.3%, and that between ratoon 1 & 2 and ratoon 3 & 4 was 0.194 or 19.4%, demonstrating that the yield values progressively reduced with the degree of ratooning. Similarly, in the second case, CFO, the yield ratios of the planted, ratoon 1 & 2, and ratoon 3 & 4 were 1.715, 1.384, and 1.048, respectively. The ratio reductions were 0.331 (33.1%) and 0.336 (33.6%), respectively, indicating a uniform decrease. The yield ratios in the second case were higher than that of the first for all crop classes because the soil type was clayey and more fertile with better water holding capacity than that of the first case, even though the rainfall of the second case (794 mm) was much less than the first (1,377 mm). These findings align with a detailed study undertaken in Brazil [18]. The yields and yield ratios of these two field observations were surprisingly high in portion 4, except for one value that is just below the upper bound. This was because these observed fields were under a yield improvement program operated by the corresponding factory [3].

The last field observation, NFO, was conducted in a farmer's field at Tak Fa, Nakornsawan, for planted cane in 2012 with the consecutive first ratoon in 2013 [14]. The actual yields reduced from 72.19 t/ha to 69.44 t/ha, and the ratios reduced from 0.882 to 0.865 (Table 4). The reduction in the actual yields was caused by annual rainfall (from 1201.93 mm to 1162.11 mm) and crop classes (from planted cane to the first ratoon). If the yield reduction was caused only by a drop in rainfall, then the yield ratio of the sugarcane crop in 2013 should be 0.882, the same as that for 2012, instead of 0.865. The yield reduction from planted to the first ratoon can be quantified by (0.882–0.865)* 100 = 1.7%. This kind of yield change evaluation cannot be performed using the conventional method of yield gap because it does not account for the rainfall factor.

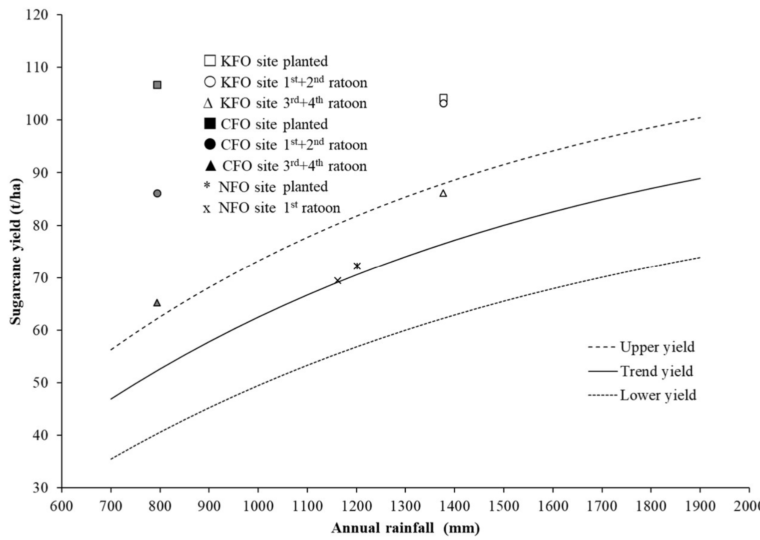

Figure 5 The positions of yields on master chart for field observations.

3.3.3 Examples of field experiments

A field experiment differs from a field observation in the sense that the former is performed under a controlled environment to produce the highest yield with specific predetermined conditions. The study by Palachai [15] explored the effects of waterlogging on the sugarcane of 12 cultivars at BEF and MEF sites. In this current study, the five most well-known cultivars in Thailand were selected for illustration, i.e., KKU99-02, KKU99-03, UT12, KK3, and LK92-11. Table 5 shows higher than 1 yield ratios for all cultivars at the BFE site but lower than 1 for the MFE site. This indicates that the combination of light soil with a 3-month inundation had no real effect on the yields of the five cultivars, although heavy soil with a 4.5-month inundation did. These two field experiments gave KK3 the best yield potential for both cases, while the least yield was LK92-11 in the first and UT12 in the second case. KKU99-02 and KKU99-03 cultivars did moderately well in both cases. The UT12, though second in the BFE case, did badly in the MFE case and is, therefore, unsuitable for heavy waterlogging (Table 5).

Table 5 Field experimental results at Mahasarakham (BFE and MFE) and Phitsanulok (PFE).

Site	Year	Rain	Upper bound	KKU99-02		KKU99-03		UT12		KK3		LK92-11	
				Yield	Ratio	Yield	Ratio	Yield	Ratio	Yield	Ratio	Yield	Ratio
BFE	2016	1411.3	89.0	127.8	**1.44**	116.1	**1.30**	130.2	**1.46**	139.3	**1.57**	108.4	**1.22**
MFE	2016	1411.3	89.0	73.6	0.83	71.3	0.80	53.0	0.60	83.5	0.94	72.1	0.81
PFE	2018	1002.9	73.4	93.1	**1.27**	124.4	**1.70**	133.1	**1.81**	85.6	**1.17**	109.4	**1.49**
PFE	2019	1546.2	92.8	41.9	0.45	41.3	0.44	71.3	0.77	114.4	**1.23**	65.0	0.70

*Note: The highlight ratios indicate better yield conditions.

The results of the third field experiment (PFE) for two consecutive years, 2018 (planted crop) and 2019 (ratoon 1) in Pitsanulok are presented in Table 5 and Figure 6. The original objective of this experiment was to compare the yields and traits of 28 sugarcane cultivars in the heavy soil of Northern Thailand. As in the previous experiment, five cultivars were selected. All five varieties of sugarcane planted crops in the moderate drought of 2018 produced good yields above the upper bound. In the very wet year of 2019, all but one was below the upper bound, with UT12 in portion 2, LK92-11, KKU99-02, and KKU99-03 in portion 1, with only KK3 being far above the upper bound (Table 5). Despite lower rainfall in 2018 (1002.9 mm) compared to 2019 (1546.2 mm), the higher yields in 2018 were due to two factors: (i) heavy rainfall on clayey soil causing waterlogging in 2019 and (ii) planted crops (2018) being a naturally higher yield than ratoon (2019). The KK3 also performed best.

The fourth field experiment was conducted at Khon Kaen Field Crop Research Center, Khon Kaen, in sandy loam soil, from 2008 to 2009, using planted sugarcane of the KK3 cultivar [17]. Five treatments were performed: (i) rainfed, (ii) 12 mm water added when pan evaporation (E_{pan}) dropped by 60 mm (W12E60), (iii) 12 mm water added when E_{pan} dropped by 40 mm (W12E40), (vi) 24 mm water added when E_{pan} dropped by 60 mm (W24E60), and (v) 24 mm water added when E_{pan} dropped by 40 mm (W24E40). The treatments (i) to (v) were subjected to total water supplies of 1291, 1423, 1482, 1555, and 1675 mm and provided yields of 86.9, 100.6, 99.4, 113.8, and 114.4 t/ha, respectively (Table 6).

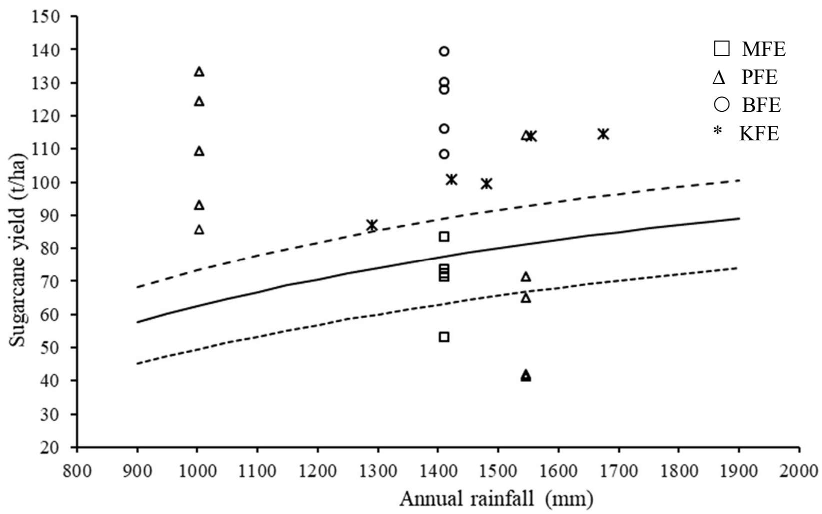

Figure 6 Sugarcane yields from the field experiments.

Table 6 Field experimental results of KK3 variety during 2008-9 in KFE.

Treatment	Total water supply (mm)	Yield (t/ha)	Upper bound (t/ha)	Ratio
No water added	1291	86.9	84.4	1.030
W12E60	1423	100.6	88.8	1.133
W12E40	1482	99.4	90.6	1.097
W24E60	1555	113.8	92.6	1.229
W24E40	1675	114.4	95.6	1.197

Figure 6 shows that all yield values at the KFE site are located above the upper bound with an increasing trend. The slope of the yield trend is steeper than that of the yield references, indicating that the KK3 is much better than the national average. The higher the rainfall, the better the yield. Table 6 reveals that the ratio of W12E60 (1.133) is higher than that of W12E40 (1.097). Similarly, the ratio of W24E60 (1.229) is higher than that of W24E40 (1.197). These results indicate that the less frequent the water supply (E_{pan}=60 mm), the better the yield ratio. This cannot be inferred using the conventional procedure of the yield gap concept due to the exclusion of annual rainfall.

4. Conclusion

Thailand has experienced extreme climate variations, affecting agricultural practices, including those of smallholder sugarcane farmers. To overcome this, Thai farmers need a tool to justify and conduct proper management practices for their farms, which also accounts for the rainfall factor. The yield gap is a common tool for cropping development, but it is difficult to obtain, involves much uncertainty, and does not account for the rainfall effect. This study proposes an alternative benchmark using the relationship between annual average rainfall and national average sugarcane yield. Data on rainfall and yield from 1961 to 2021 were checked for trend increment and detrended when necessary. An equation for the relationship between rainfall and yield was derived from a hypothesis that the derivative of yield with respect to rainfall follows an exponential decay. The study consecutively determined a set of equations on the mean, along with the upper and lower bounds. The equations rendered a master chart featuring three curves representing the mean and the upper and lower bounds. The ratio of actual yield to the upper bound yield (yield ratio) was accepted as an indicator instead of a yield gap. The study demonstrates the applications of the master chart with three field observations and four field experiments. The results show that the proposed method can better help smallholder farmers identify the causal factors of constraints than the yield gap concept. The proposed method is superior to the yield gap concept because it can be applied to the whole country, is less uncertain, more general, and simpler to utilize. Even though sugarcane breeding in Thailand has been developed since 1938 to initiate more than a hundred varieties [7], all field experiments in this study confirm that the KK3 cultivar is the best-known variety in Thailand. The proposed method can also be modified for other crops and applied in other countries.

5. Acknowledgements

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