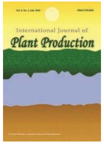

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Variations in sugarcane yield among farmers' fields and their causal factors in Northeast Thailand

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Abstract

Information on variations in crop yield among farmer fields in a specific area and their causal factors is important for efficiently targeting efforts to increase production of the crop in the target area. This study determined the yield variations and their causal factors for sugarcane grown in the service area of a sugar mill in Northeast Thailand. Two villages with the dominant sandy and clayey soil types in the area were selected as the study sites. A questionnaire was used to collect information on management practices and crop yields for the individual fields in the 2012/2013 and 2014/2015 cropping seasons for 369 fields, of which 134 were planted crop and 235 were ratoon crop. A stepwise multiple regression was used in determining the significant factors influencing yields and their order of importance. The results show great variations of sugarcane yields among farmers' fields in all crop classes, locations and years. However, their significant causal factors differed among crop classes, locations and years. The number of weedings was the most frequent yield constraint identified, followed by pre-harvest burning, number of fertilizer applications and land type. Soil type, diseases and insects, cultivar and frequency of irrigation were sporadically significant. Yield influencing factors in fields at different yield levels also varied, indicating the need for targeting improved management on individual fields. A participatory approach is suggested in the design and implementation of cultural managements for improving sugarcane yield of the individual fields.

Keywords: Yield gap; Yield constraints; Sugarcane production; Sugarcane cultivation.

Introduction

Sugarcane (*Saccharum officinarum*) is the world's major source of raw material for sugar and ethanol production. Thailand ranks fourth in the world in sugarcane production and is one of the leading sugar-exporting countries (FAOSTAT, 2015). In 2014, Thailand exported 7.4 million tons of sugar, earning some 2,900 million US$ (BOT, 2015). The harvested area of the crop in the country in 2015 totaled 1.53 million hectares, producing 106.3 million tons of sugarcane. The Northeast is the major production region, accounting for 44.2% of the country's total sugarcane harvested acreage and 43.2% of the total sugarcane production (OAE, 2016). Crop yields in Thailand, however, are still low, averaging 76.6 t ha^{-1} compared to 126.1 t ha^{-1} for Peru (FAOSTAT, 2015). Increasing the yield of the crop is, thus, a main goal of the sugar industry in the country.

In farmers' fields, the sugarcane crop is always subjected to several constraints which keep its yield lower than its potential. The difference between actual farmer yields and potential yield is generally referred to as the 'yield gap' (Gomez, 1977; Tran, 2004; Fermont et al., 2009; Lobell et al., 2009). The magnitude of the yield gap and associated causal factors are important information for efficiently targeting efforts to raise crop yields (Lobell et al., 2009). Three types of yield gap have been identified: (i) the gap between the theoretical potential yield and the highest research station yield; (ii) the gap between the highest research station yield and the highest farm yield; and (iii) the gap between the highest farm yield and the average farm yield (Tran, 2004; Lobell et al., 2009). The third type of yield gap is of special interest for practical purpose as it reflects physical and biological constraints together with socioeconomic constraints (Tran, 2004) which could be reduced by improvements in crop management or access to input. This type of yield gap reflects yield variations among farmers' fields (Lobell et al., 2005). Thus, reducing field-to-field yield variations (or field-to-field yield gaps) will eventually raise the yield level of the crop in the target area.

In any given area, variations in crop yields among the farmers' fields are a common phenomenon due to inherent spatial variability in certain biophysical constraints and differences in farmers' management practices. Within a small area, yield variations of over twofold have been reported (Calvino and Sandras, 2002; Sandras et al., 2002; Tittonell et al., 2008). Similar yield variation has also been observed for sugarcane fields in Northeast Thailand. Unpublished data collected by the Mitr Phol Group Co., the major sugar manufacturer in Thailand, showed great variations in sugarcane yields among fields, ranging from 30 to 120 t ha^{-1}. Reducing these between-field yield variations could play a critical role in raising production of sugarcane in the target area. This will require a good understanding of the factors causing these yield variations specific to the area of concern. The analysis of yield variations among fields can reveal the yield limiting constraints if yield data and associated information on the possible causal factors area available (Lobell et al., 2009; Sopheap et al., 2012). Surveys of farmers' management practices, coupled with data on soil properties and crop performance, could provide valuable information for assessing yield constraints in farmers' fields (Calvino and Sandras, 2002; Sandras et al., 2002; Inthavong et al., 2011; Sopheap et al., 2012).

Factors that could affect the yield of sugarcane in farmers' fields are numerous, including crop duration, crop type, variety, crop class, soil condition, nutrient status, climatic condition, irrigation, pests, diseases and duration of post-harvest handling (Hogarth and Allsopp, 2000). However, factors causing yield variations vary among locations. Evenson et al. (1987) and Ferraro et al. (2009) reported that variations in sugarcane yield in their studies were mainly related to crop class, while Lissen et al. (2005) identified crop cultivar and harvest time as the major causal factors and Nelson and Ham (2000) showed that soil properties were the major cause of yield variation. Tukaew et al. (2016) found that irrigation, chemical fertilizer and farm size accounted for 82% of the variation in sugarcane yield among farmers' fields under contract farming in Lopburi, Saraburi and Nakhon Sawan provinces in Central Thailand. To reduce yield variations in order to raise the mean yield requires a good understanding of the nature and strength of location-specific constraints (Neumann et al., 2010); therefore, yield constraints need to be identified separately for a specific location. In Thailand, sugarcane is usually grown under a contract with a sugar mill. The service area of a mill lies within a 50 km radius of the mill, within which production inputs and technical support are provided to farmers by the mill. Thus, the service area of a mill is a suitable target area for a yield variation analysis. In the present study, the service area of the Mitr Phu Wiang sugar mill in Northeast Thailand, a mill in the Mitr Phol Group Co., was selected as the target area. The objectives were to assess the magnitude of yield variations among farmers' sugarcane fields in this target area and to identify their associated causal factors. The information obtained will provide a basis for the mill to formulate appropriate actions for increasing sugarcane yield in its service area. The study could be a model to follow by other sugar mills, both in Thailand and in neighboring countries.

Materials and Methods

The study sites

The target area of this research was the sugarcane production area of the Mitr Phu Wiang sugar mill in Khon Kaen province in Northeast Thailand. Two villages within the area that had the predominant clayey and sandy soil types in the area were selected for this study. One was Hin Kong Village in Ban Fang District of Khon Kaen Province, located about 45 km southwest of Khon Kaen City (16° 27′ 12″ N, 102° 38′ 18″ E). The second was Kud Mak Heb village in Phu Kheo District of Chaiyaphum province (16° 22′ 35″ N 102° 7′ 43″ E), about 26 km from the Mitr Phu Wiang sugar mill. Hin Kong village had the sandy type of soils (Typic Paleustults and Grossarenic Haplustalfs) while Kud Mak Heb village had the clayey soil type (Entic Haplustolls). Both villages were under the sugarcane yield improvement program of the Mitr Phu Wiang sugar mill.

Data collection

All farmers who grew sugarcane in the two study villages were interviewed using questionnaire. Data were collected for two cropping years, i.e., 2012/2013 and 2013/2014. Altogether, data were obtained from 369 fields. Numbers of fields for the individual crop classes, cropping years and villages are given in Table 1.

Table 1. Numbers of sample fields for the individual categories of crop year, village and crop class.

Crop year	Village	Planted crop	Ratoon crop	Total
2012/2013	Hin Kong	51	66	117
	Kud Mak Heb	14	57	71
	Total	65	123	188
2014/2015	Hin Kong	39	64	103
	Kud Mak Heb	30	48	78
	Total	69	112	181
Combined	Total	134	235	369

In each cropping year, data were collected in two periods – before harvesting and after harvesting. Data collected for each field before harvesting included land type (upland or lowland), soil type, crop cultivar, crop class (planted crop or ratoon crop number), planting season (for planted crops), land preparation for planted crops or field management after harvesting of the previous crop for ratoon crops, crop starting date (date of planting for the planted crop or date of cutting the previous crop for the ratoon crop), germination percentage, gap-filling planting, kind and amount of chemical fertilizers and/or manure applied and number of applications, number of times irrigation was applied, number of weedings and method of weeding and extent of insect infestation and disease incidence. Data collected on the same field after harvesting includes pre-harvest burning, harvesting date, duration of post-harvest handling and crop yield. Crop yield for each field was determined by obtaining the weights of sugarcane on all trucks that carried the cane harvested from that field to the transfer station and then divided by the area in ha of that particular field obtained from actual field measurement using a handheld global positioning system (GPS) device. Crop duration or crop age at harvested was calculated from the crop starting date to the harvesting date of the crop in that field.

In this study, the commercial cane sugar (CCS) value of each field could not be obtained, as most of the sugarcane from these two villages were first carried to a transfer station where the cane from the different fields was mixed before being transported to the mill. Thus, only yield variations (i.e., weight of cane harvested) were analyzed for their causal factors.

Data analysis

Multiple regression analyses were used in determining the important casual factors for the yield variations. Before doing the analyses, data for the individual possible causal factors were first examined visually for their variations. Those factors that showed none or only small differences were omitted from the analysis. The remaining 12 variables were included in the multiple regression analyses for the planted crop. They were land type, soil type, month of planting, germination percentage, gap-filling planting, number of irrigations, number of fertilizer applications, amount of fertilizer applied, number of weedings, extent of insect or disease incidence, pre-harvest burning and crop duration. For the ratoon crops, month of cutting the previous crop was used in place of month of planting and field management after cutting the previous crop was added as an additional causal factor.

Considering that, in practice, improving management to narrow the yield gaps among farmers' fields could be done only within the individual crop classes in each year and each location, data analyses were done separately for the planted crops and the rotation crops in each cropping year at each village. For the ratoon crops, the initial inspection of the data revealed fairly similar distributions of sugarcane yields in the individual fields between the first and the second ratoon crops and between the third and the fourth ratoon crops at the same village within the same cropping year. To have a sufficient number of fields for a valid multiple regression analysis, the combined data of the first and second ratoon crops and the combined data of the third and fourth ratoon crops were used in the analysis. For each data set, crop yields were first fitted to all variables indicated above to identify factors that had statistically significant influence on crop yield. This was followed by a stepwise regression by which the significant factors were fitted to crop yield in a sequential order, starting with the most important factor. The values of the coefficient of determination (R^2) were used as the indicators of the extents to which yield variations could be accounted for by these factors.

Results and Discussion

Variations in sugarcane yield

Differences in means for sugarcane yields and magnitudes of yield variations were found for the different crop classes in the two study villages. Both mean yields and degrees of yield variations within the same crop class also differed in the two cropping years (Figure 1). It should be noted that the number of fields in the different crop classes varied depending on the village and the cropping year. In both villages, yields in the 2014/2015 cropping year were lower than those in the 2012/2013 cropping year for all crop classes. For example, mean yields for the planted crop at Hin Kong were 104.3 and 93.5 t ha^{-1} in 2012/2013 and 2014/2015, respectively, while mean yields for the first and second ratoon crops were 112.2 t ha^{-1} in 2012/2013 and 86.1 t ha^{-1} in 2014/2015. The yield differences between the two cropping years could be explained by the differences in the amount and distribution of rainfall. In the year 2012, rainfall was considered normal, with a total of 1,377 mm and 131 rainy days in Khon Kaen (Hin Kong village) and 1,077 mm and 97 rainy days in Chaiyaphum (Kud Mak Heb village). The year 2014, however, was a rather dry year, with the total rainfall being 943 mm and 118 rainy days in Khon Kaen and being 794 mm and 87 rainy days in Chaiyaphum.

In both years, mean yield of the planted crop was slightly higher than that of the first and second ratoon crops, while the mean yield of the third and fourth ratoon crops was the lowest, being considerably lower than that of the first and second ratoon crops (Figure 1). For example, at Hin Kong in 2012/2013, the mean yield of the planted crop was 104.3 t ha^{-1} compared to 103.2 t ha^{-1} for the first and second ratoon crops and 86.1 t ha^{-1} for the third and fourth ratoon crops. Similarly, at Kud Mak Heb in 2014/2015, mean yields of the planted crop, the first and second ratoon crops and the third and fourth ratoon crops were 106.7, 86.1 and 65.2 t ha^{-1}, respectively. Such differences in yield levels among crop classes in sugarcane had also been well documented by other research (Wood, 1986; Evensen et al., 1987; Ferraro et al., 2009: Muchow et al., 2016). In general, higher yields were obtained from clay soil than from sandy soil, as shown by the slightly higher mean yields at Kud Mak Heb (clay soil) than those at Hin Kong (sandy soil) for the corresponding crop classes in both years, except the third and fourth ratoon crops in 2012/2013 (Figure 1).

Substantial variations in sugarcane yield were observed in all combinations of crop classes, cropping years and villages, but the degrees of yield variations varied among the individual combinations. The differences between the lowest and the highest yields of nearly fourfold, or even more than sevenfold, were also observed, i.e., yield ranges were 42.2 to 158.1 t ha^{-1} for the planted crop at Hin Kong in 2012/2013 and 25.6 to 154.4 t ha^{-1} for the first and second ratoon crops at Hin Kong in 2014/2015 (Figure 1). These ranges were greater than that was observed among production fields of the Mitr Phol Group Co. in Northeast Thailand (30 to 120 t ha^{-1}). At Hin Kong, a greater yield variation was found for the planted crop in 2012/2013 (normal rainfall) (SD = 30.21 t ha^{-1}) than in 2014/2015 (low rainfall) (SD = 15.63 t ha^{-1}), but similar degrees of yield variations were observed for the planted crop at Kud Mak Heb in both years (SD = 15.90 and 15.98 t ha^{-1} for 2012/2013 and 2014/2015, respectively). However, for the ratoon crops, the degrees of yield variations appeared to be higher in the dry year (2014/2015) than in the normal rainfall year (2012/2013) at both villages (Figure 1).

Overall, the gaps between the maximum and minimum yields for the different crop classes at Hin Kong ranged from 46.3-116.0 t ha^{-1} in 2012/2013 and 62.5-132.6 t ha^{-1} in 2014/2015, equivalent to 53.8-111.2% and 66.9-187.5% of the corresponding means, respectively. At Kud mak Heb, the gaps between the maximum and minimum yields in 2012/2013 ranged from 30.1-88.4 t ha^{-1} (30.1-88.4% of the corresponding means) and in 2014/2015 varied from 59.3-74.6 t ha^{-1} (55.7-92.4% of the corresponding means). These large variations in sugarcane yields among farmers' fields indicated that there is a great potential for improvement by closing yield gaps at different yield levels, which would eventually raise the mean yield of the crop in the target area.

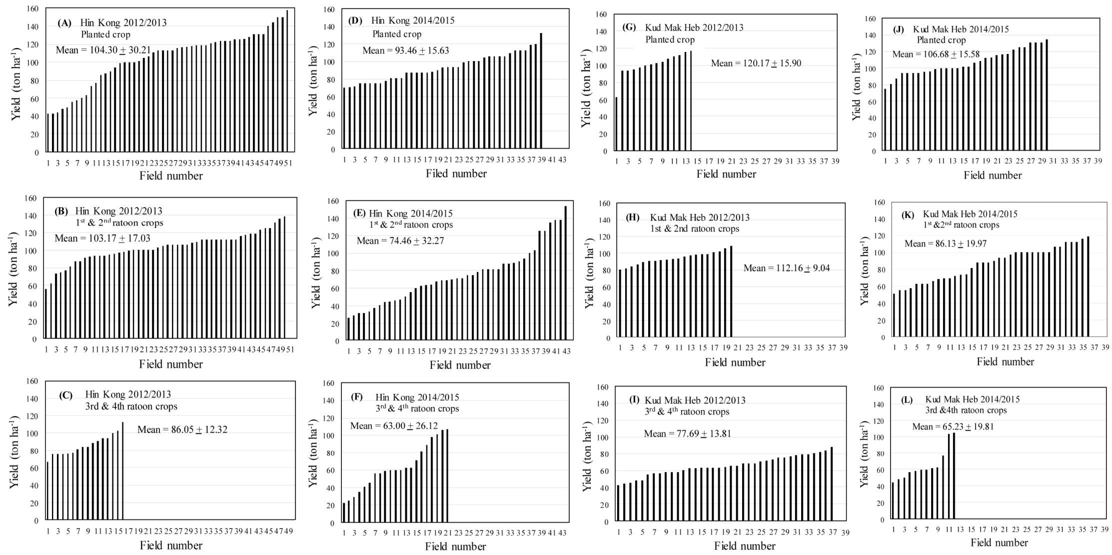

Figure 1. Variations in yield of different crop classes of sugarcane grown in the two study villages in cropping years 2012/2013 and 2014/2015.

Factors causing variations in sugarcane yield

The results of the multiple regression analyses for the causal factors of yield variations for the individual crop classes (Table 2) indicated that, for most of the crop classes, all the fitted factors (12 for the planted crop and 13 for the ratoon crops) could account for a major proportion of the yield variations in their respective analyses, with the R^2 values ranging from 0.73 to 0.99. There were, however, three analyses that the R^2 values were somewhat moderate, being in the range of 0.47 to 0.52. It was noted that the analyses that all the fitted variables could account for more than 90% of the yield variations (R^2>0.90) were those that had small numbers of observation (n = 12-16). In some analyses, the number of fitted factors was less than the intended numbers (12 for the planted crops and 13 for the ratoon crops) because of the absence of variability within certain factors. Overall, the results indicated that, for the most part, the fitted factors could explain the variations in sugarcane yield quite well. In all cases, the significant factors could explain most of the yield variations that could be accounted for by all the fitted factors (Table 2).

Table 2. Factors significantly affecting sugarcane yield for different crop classes at the two study villages in the cropping years 2012/2013 and 2014/2015.

Village/	Cropping year 2012/2013		Cropping year 2014/2015	
crop class	Factor	Cum R^{2a}	Factor	Cum R^{2a}
	Hin Kong Village			
Planted crop	1. No. of fert. applied	0.57	1. No. of weeding	0.39
	2. Land type	0.69	2. No. of fert. applied	0.43
	3. No. of weeding	0.72		
	All 12 factors (n = 51)	0.80	All 11 factors (n = 39)	0.52
1st & 2nd ratoon crops	1. No. of weeding	0.27	1. No. of weeding	0.62
			2. Starting month[b]	0.65
			3. Crop duration	0.69
			4. No. of irrigation	0.71
			5. Land type	0.76
	All 13 factors (n = 50)	0.47	All 13 factors (n = 43)	0.84
3rd & 4th ratoon crops	1. Gap-filling planting	0.36	1. No. of weeding	0.48
	2. Ratoon management	0.45	2. Germination (%)	0.51
	3. Land type	0.52	3. Ratoon management	0.68
	4. No. of weeding	0.66		
	5. Pre-harvest burning	0.77		
	6. Amount of fertilizer	0.88		
	All 13 factors (n=16)	0.96	All 11 factors (n = 21)	0.77
	Kud Mak Heb Village			
Planted crop	1. Gap-filling planting	0.26	1. Pre-harvest burning	0.39
	2. Cultivar	0.49	2. No. of fert. applied	0.71
	3. Pre-harvest burning	0.53	3. No. of weeding	0.77
	4. Amount of fertilizer	0.72	4. Diseases & insects	0.80
	5. No. of weeding	0.77		
	All 11 factors (n = 14)	0.94	All 12 factors (n = 30)	0.87
1st & 2nd ratoon crops	1. Soil type	0.15	1. Pre-harvest burning	0.56
	2. Starting month[b]	0.54	2. No. of weeding	0.73
	3. Crop duration	0.59	3. No. of fert. applied	0.76
	4. Germination (%)	0.63		
	All 13 factors (n = 20)	0.68	All 11 factors (n = 35)	0.79
3rd & 4th ratoon crops	1. No. of weeding	0.25	1. Pre-harvest burning	0.62
	2. Crop duration	0.30	2. No. of fert. applied	0.93
	3. Pre-harvest burning	0.45		
	All 13 factors (n = 37)	0.52	All 9 factors (n = 12)	0.99

[a] Cumulative R^2.
[b] Month of harvesting the previous crop.

The factors that had statistically significant influences on sugarcane yield and their degrees of importance, however, varied depending on the crop class, the location (village) and the year. For example, at Hin Kong in 2012/2013, the analyses identified three significant factors (number of fertilizer application, land type and number of weedings) for the planted crop, but identified only one factor (number of weedings) for the first and second ratoon crops, while six factors (gap-filling planting, ratoon management, land type, number of weedings, pre-harvest burning and amount of fertilizer applied) were identified for the third and fourth ratoon crops. Likewise, at Kud Mak Heb in 2012/2013, five significant factors (gap-filling planting, cultivar, pre-harvest burning, amount of fertilizer apploed and number of weedings) were identified for the planted crop, but three factors (soil type, crop duration and germination percentage) were identified for the first and second ratoon crops and only three (number of weedings, crop duration and pre-harvest burning) were significant for the third and fourth ratoon crops (Table 2).

The order of importance of the significant factors also differed for the different crop classes, locations and years. For example, for the planted crop at Hin Kong, the number of fertilizer applications ranked first in importance, followed by land type and number of weedings in 2012/2013, while in 2014/2015, the number of weedings was the most important factor, followed by the number of fertilizer applications. On the contrary, for the first and second ratoon crops at Kud Mak Heb, soil type, month of harvesting the previous crop (crop starting month), crop duration and germination percentage were the significant factors in order of their importance in the 2012/2013 cropping year, but pre-harvest burning, number of weedings and number of fertilizer applications were the important factors in order of importnace in the 2014/2015 cropping year (Table 2).

Table 3 presents the frequency of occurrence and distribution of each significant causal factor in the different crop classes, years and locations. Clearly, the number of weedings stands out as the most frequent causal factor for the yield variations of sugarcane, appearing in all but two combinations of crop class, year and location. Pre-harvest burning was second in frequency, mainly affecting sugarcane yield at Kud Mak Heb for all crop classes. The number of fertilizer applications was third, being important for the planted crop at Hin Kong in both years, while having a significant influence on yield of all crop classes at Kud Mak Heb in the 2014/2015 cropping year. The amount of fertilizer applied, however, was significant only for the third and fourth ratoon crops at Hin Kong in 2012 and the planted crop at Kud Mak Heb in the same year. It should be noted that the number of fertilizer applications and amount of fertilizer applied were highly correlated (data not shown), implying that the effect of the amount of fertilizer partially accounted for by the effect of the number of fertilizer applications.

The next most frequent factor was land type, i.e., upland or lowland. This factor was important only at Hin Kong which had sugarcane fields in both upland and lowland, but was unimportant at Kud Mak Heb which had most of the sugarcane field in the upland (Table 3). Crop duration and crop starting month appeared to be important for the ratoon crops in a certain year at each location, while germination and gap-filling planting were important in two of the crop class combinations. Ratoon management had significant influence in the third and fourth ratoon crops grown on sandy soil at Hin Kong, but were not important on clay soil at Kud Mak Heb.

The remaining factors, i.e., soil type, diseases and insects, cultivar and number of irrigation applications, appeared as significant factors only once in all the crop class combinations (Table 3). Overall, number of weedings, pre-harvest burning and number of fertilizer applications were the dominant factors influencing the variations in sugarcane yield, appearing frequently as significant factors. Other factors appeared as important less frequently and their significant effects were rather sporadic in occurrence.

Table 3. Distribution of significant causal factors for the variations of sugarcane yield in different crop classes, locations and years.

Causal factor	Hin Kong village						Kud Mak Heb village					
	Planted crop		1^{st}&2^{nd} ratoon		3^{rd}&4^{th} ratoon		Planted crop		1^{st}&2^{nd} ratoon		3^{rd}&4^{th} ratoon	
	2012	2014	2012	2014	2012	2014	2012	2014	2012	2014	2012	2014
Number of weeding	X	X	X	X	X	X	X	X		X	X	
Pre-harvest burning					X		X	X		X	X	X
Number of fertilizer application	X	X						X		X		X
Land type	X			X	X							
Amount of fertilizer					X		X					
Crop duration				X					X		X	
Crop starting month				X					X			
Germination percentage						X			X			
Gap-filling planting					X		X					
Ratoon management					X	X						
Soil type									X			
Diseases and insects								X				
Cultivar							X					
Number of irrigation				X								

The effects of the number of weedings on yield of sugarcane for the different crop classes at the two study villages are shown in Figure 2. For the planted crop at Hin Kong, one weeding did not make any difference from no weeding. Yield response was obtained when weeding was done two or three times and this was consistent in both years. For the planted crop at Kud Mak Hep, no yield response to weeding was observed in both years. For ratoon crops, yield responses to weeding were consistently obtained at both villages in all years. Their magnitudes, however, varied depending on the site and year. For example, at Hin Kong, three weedings gave nearly 40 t ha^{-1} higher yield than no weeding in 2012/2013, but gave more than 70 t ha^{-1} higher yield in 2014/2015. At Kud Mak Heb, yield responses to two or three weedings were about 35 t ha^{-1} in 2012/2013 and about 45 t ha^{-1} in 2014/2014 (Figure 2). These results were based on mean yields. Certainly, substantially greater yield responses should be obtained on the individual field basis. Evidently, weeds were a major problem, but their seriousness varied among the individual fields.

The effects of pre-harvest burning on crop yield were prominent at Kud Mak Heb in the 2014/2015 cropping year. Lower yields were obtained from the burned fields than from the unburned fields for all crop classes. Mean yields of the burned fields and the unburned fields were 88.4 and 110.1 t ha^{-1}, respectively, for the planted crop, 64.1 and 89.1 t ha^{-1}, respectively, for the first and second ratoon crops and 65.3 and 81.6 t ha^{-1} for the third and fourth ratoon crops (data not shown). On the contrary, in the 2012/2013 cropping year, the effects of pre-harvest burning at this village were unclear. It is well established that weight loss of burned sugarcane could occur after harvesting, particularly when transportation to the mill was long delayed (OCSB, 2007). In the 2014/2015 cropping year at Kud Mak Heb, there was an incidental wildfire that spread out over a large area. This was an unplanned burning which caused a long delay in postharvest handling of sugarcane. The substantially lower yields of the burned fields compared to the burned fields at this location in that year might have partially been the consequence of this unplanned pre-harvest burning.

Effects of other factors could be shown in a similar manner for the respective crop class in the year and location in which they were significant.

The above results reveal the complexity of the expression of the yield influencing factors for sugarcane under different environmental and management conditions. This might be because sugarcane is a long duration crop and in the present study, the crops in the individual fields had the durations ranging from 8 to 14 months. Over such a long period, the crops in the individual fields should have encountered both favorable and unfavorable conditions, but at different growth stages as their starting dates differed in the different fields. Certainly, the differences in rainfall between the two years and in soil types between the two locations should have influenced the differential responses of the crops to the various yield influencing factors. Furthermore, in any season, the effects of those factors affecting crop yield in farmers' fields were largely confounded with each other and the effects of some factors might be overridden or counteracted by the effects of other factors. Consequently, the factors that showed significant effects on sugarcane yield differed for the different crop classes, locations and years. Because of this complexity there is no universal solution for closing the gaps in sugarcane yields among farmers' fields and attention should be focused on raising the yield of the individual fields with the management practices specific to their conditions.

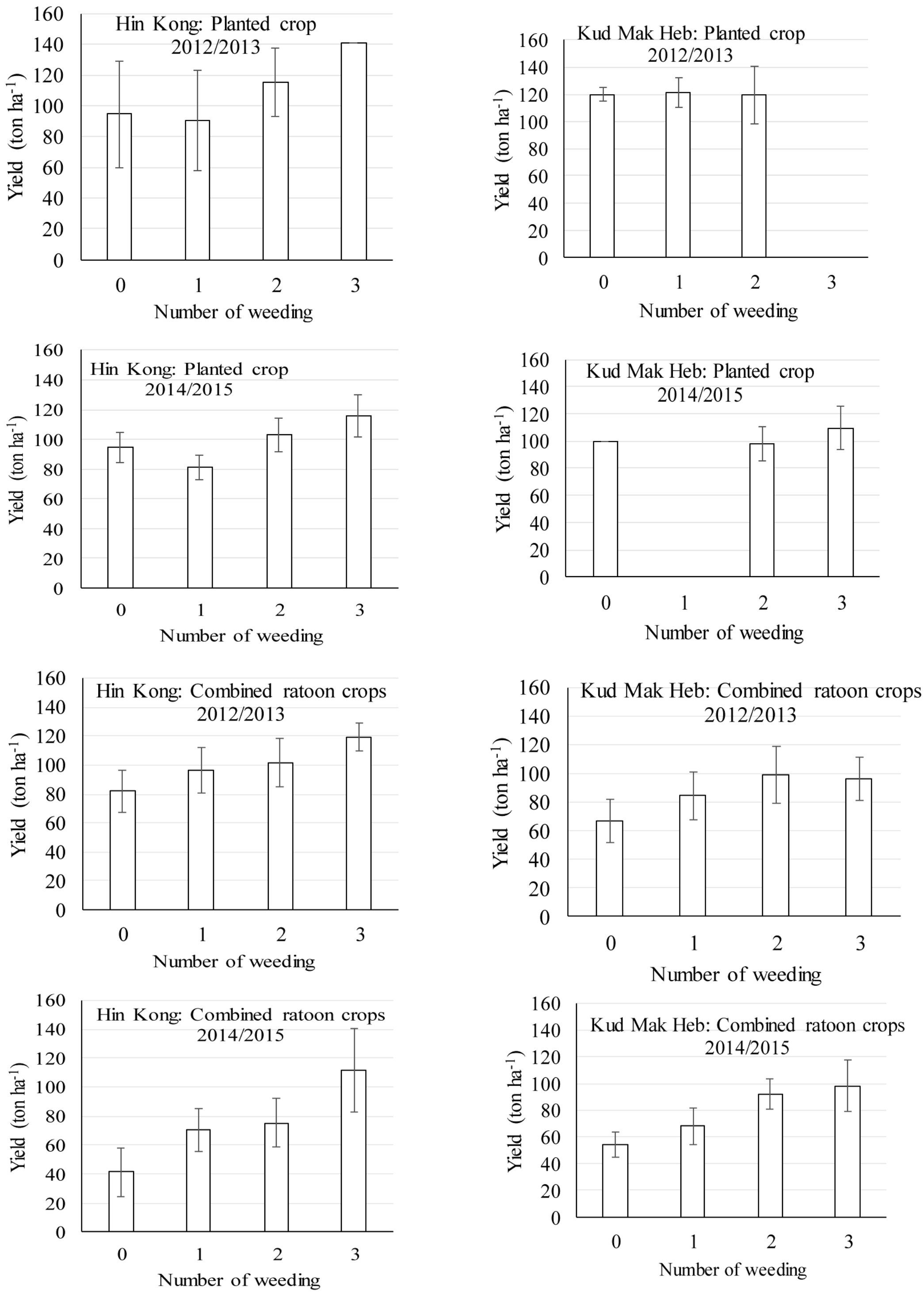

Figure 2. Effects of number of weeding on yield of sugarcane in different crop classes.

Factors causing sugarcane yield gaps at different yield levels

Tables 4 and 5 show selected fields at different yield levels and associated significant yield influencing factors for the first and second ratoon crops at Hin Kong in 2012/2013 and at Kud Mak Heb in 2014/2015, respectively. At Hin Kong, the highest yield level was obtained from lowland fields with three weedings, while fields with no weeding in the upland area gave the lowest yield level. Those with a moderately high yield level also had three weedings but were in the upland area, while those with a moderately low yield level had fewer weedings (1 or 2 times) and were grown in either the upland or the lowland areas. Among the fields with a moderately low yield level, the one in the upland area with one weeding had somewhat lower yield than the other two lowland fields with two weedings (Table 4). These results indicated that, for these two factors, the fields with high yield level had favorable conditions for both factors and the fields with low yield level had unfavorable conditions for both factors, while the fields with moderately high or moderately low yield levels had one out of two of the favorable conditions. No clear relationship between crop yield with the other three factors, i.e., month of harvesting the previous crop (crop starting month), crop duration and frequency of irrigation, was observed in these selected fields (Table 4). This might be because the number of weedings was the dominant influential factor on sugarcane yield for this crop class at this location in this year. This factor alone accounted for 62 % of the total yield variation, while crop starting month, crop duration and frequency of irrigation had rather small effects, adding only small percentages to the cumulative R^2 when they were sequentially included in the regression model (Table 2).

A clearer relationship between favorable conditions of influencing factors and yield levels of sugarcane was shown in the first and second ratoon crops at Kud Mak Heb in 2014/2015 (Table 5). For this crop class, pre-harvest burning, number of weedings and number of fertilizer applications were the significant factors influencing yields, with pre-harvest burning being the dominant factor (Table 2). It can be seen that those fields in the high yielding group (112.5-118.8 t ha^{-1}) had favorable conditions for all these three factors, i.e., no pre-harvest burning, three weedings and two fertilizer applications. On the contrary, those fields in the low yielding group (51.3-55.5 t ha^{-1}) had unfavorable conditions for all three factors, i.e., pre-harvest burning, no or one weeding and one or two fertilizer applications. Those fields with moderately high yield level (93.8-100.0 t ha^{-1}) had a less favorable condition for one factor, i.e., two weedings, while those with a moderately low yield level (68.8-73.0 t ha^{-1}) had either one unfavorable main factor (pre-harvest burning) or two unfavorable factors (pre-harvest burning and no or two weedings). These results indicated that the number of yield constraints and the magnitude of their effects varied from field to field. Similar findings were obtained from the study on the causal factors of yield variations in cassava by Sopheap et al. (2012).

The above results also suggest that cultural management to improve sugarcane yield needs to be targeted specifically for the individual fields. A participatory approach is suggested in designing the improved management for the individual fields. This could be done by presenting the results of the present study to the individual farmers, discussing with them on the constraint factors for each field and involving them in the design of improved cultural managements for each of their fields. Visits to the high yielding fields should be arranged for farmers to learn from the field owners how they were able to obtain a high crop yield. Necessary support should also be provided by the mill to enabling farmers to implement the designed management practices.

Table 4. Sugarcane yield for selected fields in the different yielding groups and associated yield-influencing factors, first and second ratoon crops at Hin Kong in the 2012/2013 cropping year.

Yielding group	Yield (t ha^{-1})	No. of weeding	Starting month[a]	Crop duration (month)	No. of irrigation	Land type
Low	25.63	0	December	16.50	0	Upland
Low	28.75	0	February	12.50	0	Upland
Low	31.25	0	March	12.50	0	Upland
Moderately low	50.63	1	February	12.50	0	Upland
Moderately low	55.00	2	March	12.50	1	Lowland
Moderately low	59.38	2	March	10.50	1	Lowland
Moderately high	75.00	3	March	11.50	0	Upland
Moderately high	78.13	3	February	12.00	0	Upland
Moderately high	81.25	3	February	11.50	0	Upland
High	135.63	3	April	10.50	0	Lowland
High	138.13	3	December	13.50	0	Lowland
High	154.38	3	January	10.50	0	Lowland

[a] Month of harvesting the previous crop.

Table 5. Sugarcane yield for selected fields in the different yielding groups and associated yield-influencing factors, first and second ratoon crops at Kud Mak Heb in the 2014/2015 cropping year.

Yielding group	Yield (t ha^{-1})	Pre-harvest burning	No. of weeding	No. of fertilizer application
Low	51.25	burned	0.00	2.00
Low	55.00	burned	0.00	1.00
Low	55.50	burned	1.00	1.00
Moderately low	68.75	burned	3.00	2.00
Moderately low	71.88	burned	0.00	2.00
Moderately low	73.00	burned	2.00	2.00
Moderately high	93.75	unburned	2.00	2.00
Moderately high	100.00	unburned	2.00	2.00
Moderately high	100.00	unburned	3.00	2.00
High	112.50	unburned	3.00	2.00
High	116.25	unburned	3.00	2.00
High	118.75	unburned	3.00	2.00

Conclusions

This study revealed great variations in sugarcane yield in the service area of the Mitr Phu Wiang sugar mill in Northeast Thailand. Significant yield constraints were found to vary among crop classes, locations and years, both in the number of constraints and the magnitude of their effects. The constraints affecting crop yield in the fields at different yield levels also varied, with more factors affecting the low yielding fields and fewer factors affecting fields with higher yield levels. Thus, to improve sugarcane yield in the target area, a universal solution will not work. Rather, improved management needs to be designed and targeted specifically for the individual fields. A participatory approach is suggested in the design and implementation of cultural managements for improving crop yield of the individual fields.

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