Yield Constraints of Mango Orchards in Thailand

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Abstract

Farmers in Phrao, North Thailand, planted a large number of mango orchards on a "trial and error" basis and with varying success. In 1993, a Comparative Performance Evaluation (CPE) of 45 mango orchards was made to identify land and management aspects that condition the level of productivity.

The orchards are situated on podzolic soils on hills, footslopes, and terraces that dry out deeply during the dry season. They contain a mix of mango, lychee and longan trees. Yields are expressed in farm-gate prices since middlemen purchase the produce from farmers 'on the tree'. With many orchards having 'low' yields and 18 having 'zero' yield, the yield data have a loglinear distribution. A model to estimate 'when yields can be expected' was developed by logistic regression, as was a linear multiple regression model for logarithmic transformed yields of the 'non-zero' group. A model to estimate Ln(Yield+1), using data from all sites, estimates individual contributions to the total yield gap by specific yield constraints. The model suggests that yields increase if:

- It is not an 'off' year (caused by biennial bearing behavior of mango; use of growth regulators may remedy this).
- The orchard is situated on a hill or on soils with a relatively high pH or poor water holding capacity (mostly shallow soils with SCL as topsoil; water stress causes crop dormancy and induces flower initiation).
- The possibility exists to apply supplemental irrigation. Orchards having a growth flush or in a fruit bearing stage require adequate water management including supplemental irrigation.
- In established orchards weeding by tractor leads to root pruning that affects the tree's physiological cycle.
- Pruning is practiced (this is normally also done to remove branches damaged by stem boring caterpillars; all orchards suffered from this serious problem).
- Spraying by motor sprayer dispenses pesticides (preferably Azodrin) deep into the canopy.

The model suggests that environmental factors (location and pH) account for some 30% of the yield gap, management factors for 49% and the year effect (species attribute) for 21%. Management of mango orchards must always use up-

to-date technology since responses provide exponential returns. The management requirements of mango orchards demand not only that farmers are knowledgeable and experienced but also that a well-informed extension service collaborates closely with researchers.

1. Study objective

Since the mid-seventies, farmers in Phrao planted a large number of orchards with mango as the most prominent fruit tree. Sales continued to be profitable and farmers made great efforts to improve their orchard's productivity. However, lack of experience led to a "trial and error" type of management (Wangchuk 1992) that can partly be attributed to a disparity in access to knowledge. This is caused by the limited attention of extension services for some settler categories (Marzan 1992) and by problematic technology transfer to settlers with a low level of education (Polprasid 1986). The above resulted amongst others in a rather random establishment of orchards with varying success rates (**Figure 1**). Areas involved concern mostly resettlement schemes managed by the Phrao Cooperative Land Settlement Project. Planning of the scheme was based on land allocation on an 'equal area' principle and not on evaluation of the suitability of land for anticipated land uses (Schapink 1992). Teshome (1992) reports that gross-margins from fruit crops are up to ten times those obtained from other crops in Phrao. Dissimilar gross-margins and dissimilar access to credit that relates to the presence of a land title deed[1] created dissimilar access to inputs such as irrigation water, NPK and pesticides (Polprasid 1986). The costs involved in planting an orchard, the long waiting period till returns can be expected, and the 'trial and error' approach add up to a considerable risk to fruit-farmers. In Phrao, pests like stemborers (caterpillars[2]) that affect mango trees to the extent that several orchards were being uprooted in 1993 amplify these risks. However, if successful, orchards provide a lasting high income (Waramit 1992).

Comparative Performance Evaluation (CPE) allows studying the impact of differences in land supplying conditions and management on the productivity of orchards and makes the 'trial and error' approach redundant.

2. Study area

Phrao is located in North-Thailand, 80 km from Chiang Mai, and measures 1,339 km^2. It has a population of 50,487 scattered over 93 villages. The region consists of an oval floodplain (alluvial soil complex) surrounded by terraces (under rainfed agriculture) and mountains (national park); see **Figure 1**. In North Phrao, only 34 orchards existed in 1977 (within the 200 km^2 studied[3]). In 1984 their number had

1 Land titles were held for 54 of the 64 orchards surveyed.
2 Most likely larvae of the Cerambycid beetle ssp. called *Rhytidodera simulans* (FAO 1986[b]).
3 Counts are based on two sets of aerial photographs (1977 at scale 1:15.000 and 1984 at scale 1:20.000); field verification in 1993.

increased to 144 even though 8 of the old orchards were uprooted. The orchards are found on three terrain units, i.e. in 1984: hills (29x), footslopes (48x), and terraces (67x; **Figure 1**). A general climatic overview is shown in Figure 2. The undulating fluvial terraces (400-500 masl) are composed of gravel and sand with some clayey inclusions that date back to the Upper-Tertiary to Lower-Pleistocene; the hills (500-1800 masl) consist of Carboniferous sediments such as quartzite, sandstone, siltstone, shale and chert that originate from meta-sedimentary rocks[4] (RLE 1993, Intrasuta 1983).

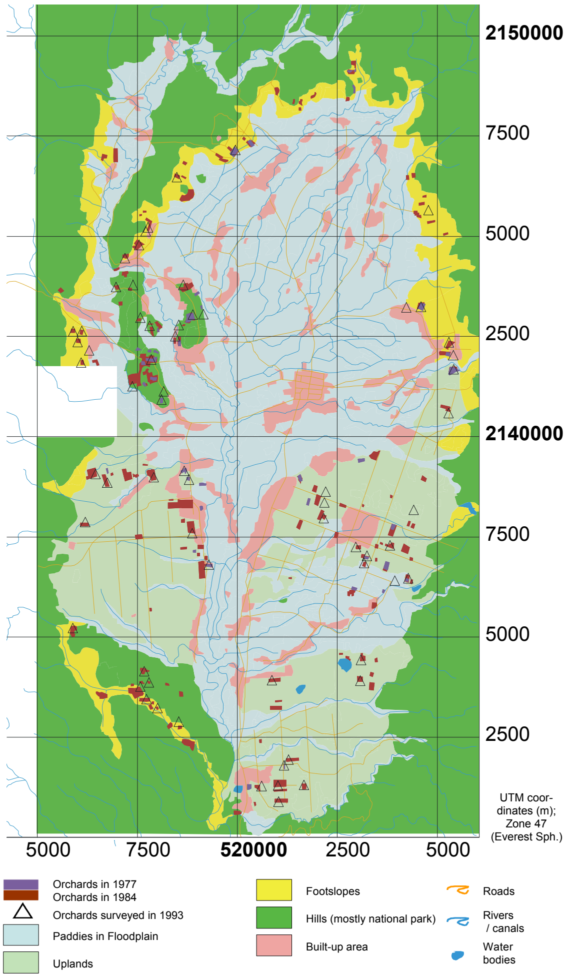

Figure 1. Map of North Phrao showing the location of orchards by terrain unit in 1977 and 1984 plus those sampled in 1993. (Terrain map based on RLE 1993 at 1: 50.000).

4 Intrasuta (1983) states that metamorphic rocks in hills consist of orthogneiss, paragneiss and high-grade schist (Cambrian to Ordovician) plus low-grade phyllite, quartzite and slate (Devonian).

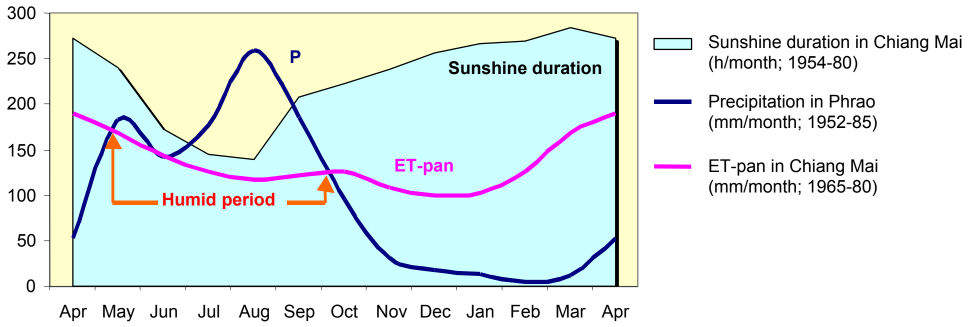

Figure 2. P - ET_{pan} diagram for Phrao.

3. Study method

In 1993, “old” (present in 1977), “young” (present in 1984), and “recently established” orchards (since 1984) were sampled, i.e.: hills 16x, footslopes 20x, and terraces 28x (total of 64). This number represents about 50% of the total number of orchards present in 1984 (**Figure 1**). The availability of farmers strongly influenced the selection of sites; the intention was was to sample an equal number of orchards on each terrain unit, with a minimum of 5 orchards in each age category. Collected data covered every aspect of operation sequences followed and a set of easy to measure land properties. All data were entered in the Land Use Database. In a spreadsheet, for applicable parameters, the query results were generalized to achieve a reduced number of nominal classes. Next, site-specific soil data were added and categorical data normalized. The data were then screened with descriptive statistics and used for model estimation[5]. Next, the contribution of individual constraints to the overall yield gap was estimated.

4. Descriptive statistics

Most orchards surveyed consisted of a mix of mango (*Magnifera indica L.*)[6], lychee (*Litchi chinensis Sonn.*), and longan (*Dimocarpus longan Loureiro*) trees. Mango was found in 49 of the 64 orchards surveyed, i.e. in all orchards on hills and footslopes and in 13 of the 28 orchards sampled on terraces. Footslopes had relatively more pure mango stands and terraces had relatively fewer mango trees (**Table 1**). Tree counts revealed that mango trees make up 34, 42 and 23% of orchards on hills, footslopes and terraces respectively. Orchard sizes were inferred from aerial photographs flown in 1984 and from step counting in the field and a Spot-Pan image of February, 1993. They varied from 0.12 to 8.0 ha (average of 1.6 ha).

5 Systat v.7.0.1 software (© 1997 SPSS Inc.).

6 There are more than one hundred local mango varieties in Thailand; prominent ones are Ok-Rong, Nangklangwan, Rad, Pimenmun, Kwiewsawoey, Namdokmai, Fahlan, Petchbanlad, Chackhuntip, and Salaya (Subhadrabandhu 1986).

Table 1. Count of surveyed mango orchards in Phrao by terrain unit

	Hills	Footslopes	Terraces	Total
Mango alone	**8**	**13**	**2**	**23**
Mango + Lychee	**1**	**1**	**2**	**4**
Mango + Longan	**5**	**3**	**3**	**11**
Mango + Lychee + Longan	**2**	**3**	**6**	**11**

4.1 Yields

Middlemen buy the produce before harvest, i.e. on the tree, and arrange the actual harvesting (April-June) between themselves. Thus, when interviewed, farmers could only report the 'farm gate' lump sum received for their crop. The bargaining skills of the farmer and middleman, the total quantity involved, and the quality of the fruit, all influence the price. In 1993, farm-gate mango prices varied from 10-30 Bath/kg (40-120 US-$ cents/kg)[7].

Yield data from 47 orchards were available[8] for analysis; they were expressed in '000 Bath/ha. Yield data were estimates by dividing the proceeds by mango sales by the orchard size and the fraction of mango trees per orchard. In 18 orchards surveyed, there was "0" mango yield. The many zero yields and many cases with low yield resulted in a non-normal distribution of the yield data. **Figure 3**[a] shows the Z-scores. In theory, a lognormal distribution fits well to such data and to data that cannot assume negative values (such as yields). To establish data normality as required for linear regression, logarithmic data transformation is applied. **Figure 3**[b] shows the results of a natural log transformation. The "0" yields are all omitted; the Z-scores of the 29 remaining yield data show a linear pattern. Testing the Ln(yield) data for normality by the 2-tail Kolmogorov-Smirnov test provided a P-value of 62.3%, which is acceptable. Adding the 18 "0" yields by using the arbitrary Ln(Yield+1) transformation (**Figure 3**[c]) provided Z-scores that were partly linear, partly non-linear; when tested together, the transformed data were not normally distributed (**Figure 3**[d]). Transformations like aY^n (with $n<0$) did not result in further improvement because of the large number of "0" yields.

Initial models proposed were based on the observation that certain orchards produced fruit (according to a lognormal distribution), while others did not. They were (see sections 5 and 6):

- A model assuming a "0,1" Poisson distribution indicating "when yields can be expected", and estimated through logistic regression. Estimated is the S-shaped model: Yield probability = $e^{lp} / (1+ e^{lp})$, where 'lp' stands for the linear prediction: $a + b.X_1 + c.X_2+….z.X_z$ (a to z are coefficients and X_1 to X_z independents; Jongman *et al*. 1987).
- A model, established through linear multiple regression, assuming normal distribution of logarithmic transformed yields for the "1" population.

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7 The highest reported yield was 250,000 Bath/ha. At 10 Bath/kg this translates into 25 t/ha.
8 2 Farmers could not provide reliable yield information.

Simultaneous use of different models is justified if (it is assumed that) each represents a different crop physiological mechanism and each defines its contribution to the final production independently. It is assumed that these mechanisms are 'flower initiation' and 'fruit formation' (from flowering to fruit maturity). This assumption tallies with the observation that several very lush and fully-grown orchards in Phrao failed to produce any fruits. The perfect continuum of yield data gathered (**Figure 3**[a]) hardly supports the assumption made. Therefore, the Ln (Yield+1) data were also subjected to multiple linear regression in spite of their non-normal behavior (section 7).

All models proposed referred to weighed yield data. The weighing factor used was "orchard size x fraction of mango trees in the orchard". Weighing aimed to reduce the effect of "the total quantity involved" on sale proceeds and to reduce the effect of unequal mango tree densities. After the three models were established, all results were evaluated to identify the "best" approach to estimate the contributions of individual constraints.

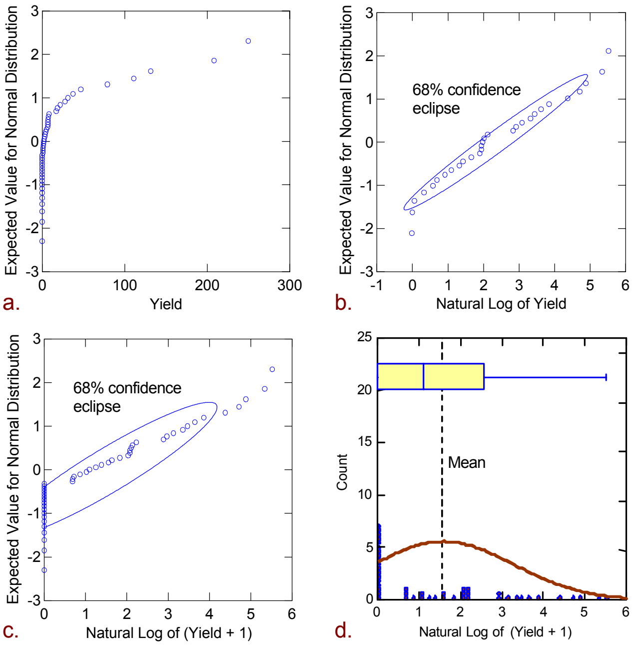

Figure 3. Transformation of mango yield data ('000 Bath/ha)
a: Z-Scores of original yield data
b: Z-Scores of Ln(yield) with '0' yields omitted[9]
c: Z-Scores of Ln(yield+1)[10]
d: plot of the distribution of Ln(yield+1)

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9 The probability that Ln(yield) is normally distributed is 62.3% (Kolmogorov-Smirnov 2.34, 1.64).
10 The probability that Ln(yield+1) is normally distributed is 3.6% (Kolmogorov-Smirnov 1.57, 1.69).

4.2 Age of trees, biennial bearing and canopy cover

The age of mango trees in the surveyed orchards varied from 3-35 years (average of 15 years). Two orchards had only trees less than 5 years of age and did not produce any fruits. Purseglove (1977) states that mango starts bearing fruit around its fifth year and comes to full production at the age of 20. Farmers (33x) reported ages of 3.5 to 8 years with a median of 5 years (**Figure 4** left). The two orchards with an alleged age of less that 5 years were excluded from further analysis. Linear regression with the remaining sites produced the following equation (Adj.-R^2 of 2.5% and a regression coefficient with a non-significant P): Ln(Yield+1) = -0.81 + 0.87 * Ln (Tree Age); see **Figure 4** middle (n=45).

Mangos have the tendency to biennial fruit bearing and may only produce one good crop every 3-4 years depending on weather conditions; they require strongly marked seasons and dry weather for flowering and fruiting (Purseglove 1977). The pattern of yields over the years was not studied in detail because the reliability of information on annual sale proceeds supplied by farmers for 5 individual years was considered poor. Instead, estimates of average sale proceeds for the entire 5-year period were collected (**Figure 4** right). Both sets of yield data are significantly related (Adj.-R^2 of 32%), although the 1993 sale proceeds were on average lower than those obtained during the preceding 5 years. In 1993, several sites had a relatively good yield (8x) while others produced relatively less (11x); see the 99% confidence lines in **Figure 4**. This qualitative information is coded as 1, 0, and -1 (relatively good, average, and poor respectively), and used as such during model formulation.

The canopy cover of orchards (including the possible contribution by "other" trees) varied from 10 to 95% of the ground surface (median of 75%). The canopy cover data are not related to tree age (correlation of 8%) or to yield (Adj.R^2 of 3%); cover data of individual mango trees were not collected. Canopy cover is further discussed under 'Weeding' (page 9).

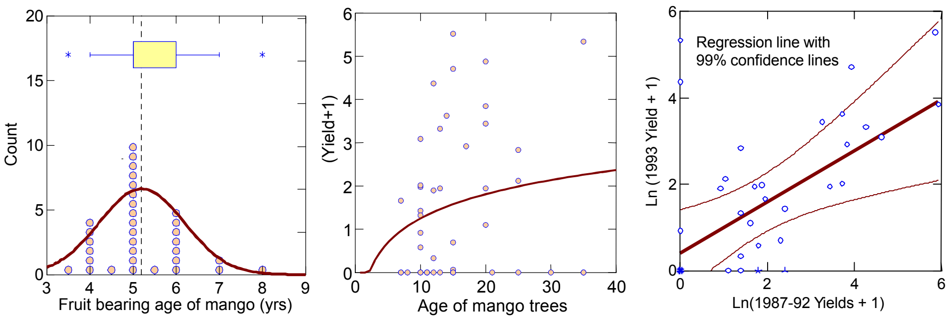

Figure 4. Impacts of tree age and biennial bearing on mango yields.

4.3 Cropping patterns

Intercropping and grazing between the trees are common during the early years of orchard establishment. In several orchards (10x) intercropping with annual crops took place, viz. 6 times with pulses (mainly soybean) and 4 times with other crops. The last group was related with relatively low mango yields and was confined to relatively old orchards (**Figure 5**). For each orchard type, a co-variable was used during model formulation.

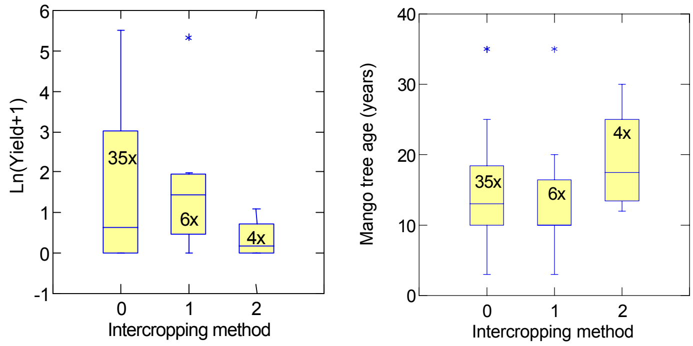

Figure 5. Intercropping of annuals in orchards versus mango yields and mango tree age.
0 = none, **1** = with pulses (mainly soybean), **2** = other (maize, tobacco, chilies, sweet potatoes, etc.)

4.4 Soil / Terrain characteristics

All sites were located on podzolic soils (Dystropepts and Paleustults) that dry deeply during the dry season (DLD 1976). The texture of the topsoil was estimated by the "texture-by-feel" method (Thien 1979). **Table 2** shows that texture classes and land units are related (Pearson Chi^2 Probability of 1.7%). **Figure 6**$^{a+b}$ shows that yields were relatively low on terraces and on hills with loamy sand topsoils. ANOVA showed both relations to be not significant. Soils with SCL topsoils received relatively often a 'poor' Water Holding Capacity verdict (WHC[11]).

Table 2. Count of orchards differentiated by terrain type, texture of the topsoil, and soil water-holding capacity (WHC)

texture:	SC			SCL			LS			All	
WHC:	poor	other	All	poor	other	All	poor	other	All	poor	other
Hill	2	2	**4**	3	2	**5**	1	4	**5**	6	8
Footslope	0	5	**5**	4	10	**14**	0	1	**1**	4	16
Terrace	2	5	**7**	1	2	**3**	0	1	**1**	3	8
All	4	12		8	14		1	6			

11 Assessed by the farmer as 'poor' if the sub-soil dried within days after a rain shower and as 'good' if this took around one week (intermediate values did not occur).

Figure 6[c] shows how the soil-WHC affects yields (ANOVA P of 5.3%). Soils with a poor WHC had higher yields. This can be explained by the fact that soils with adequate water contents throughout the year promoted luxuriant growth, no flowering, and poor fruit production (Purseglove 1977). If step-wise forward regression, with all classes of terrain, texture and WHC as co-variables was done, only WHC would significantly explain 6.3% of the variability of Ln(Yields+1).

Slope angles within orchards varied from 0-20% (median of 4%); the data were poorly correlated with yield (Pearson coefficient of 11%). The pH of the topsoil (measured with a field kit; range of 4.0-8.0; median of 6.0) and yield had a correlation of 17%. The farmer's assessment of the fertility status of the orchard soil is positively though not significantly correlated with yield (**Figure 6**[d]).

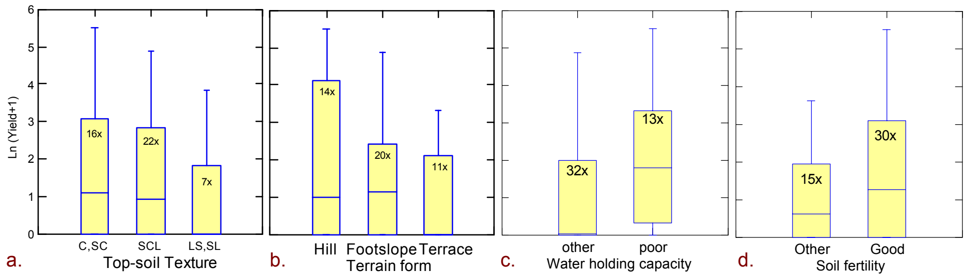

Figure 6. Mango yields plotted against land and soil characteristics.

4.5 Operations and Observations

Planting

Mango is planted during the rainy season that lasts from May to September. Generally, purchased seedlings are planted without applying any inputs (30x) or with application of farmyard manure, NPK, and/or the insecticide 'Furadan' (9x). Ten farmers planted mango seeds without use of any soil amendments or pesticides.

Pruning

Annual pruning takes place during July and August. Half of the farmers pruned their trees; the impact of pruning on yields was clear (**Figure 7**[a]). Linear regression showed that pruning explains significantly 12.6% of the total variability in yields: Ln(Yield+1) = 0.81 + 1.31 (if pruning is done).

Weeding

Only 2 out of 45 farmers did not weed their orchards. Normally, weeding started during the first months of the rainy season (May to July) and ended in the period Aug.-Oct. (**Figure 7**[b]). Weeding was done manually (23x), by 2-wheel tractor (18x) or by 4-wheel tractor (4x). **Figure 7**[c] shows the clear impact of mechanical weeding on mango yields. It explained 5% of the overall yield variability with a P of the coefficient of 7%. The relation between yield and weeding is: Ln(Yield+1) =

1.06 + 0.921 (if weeded by tractor). The canopy cover of all trees in the orchard (%) is significantly correlated with the use of tractors (**Figure 7**[d]); the two-sample t-test showed that the distributions shown are significantly different (P=0.4%).

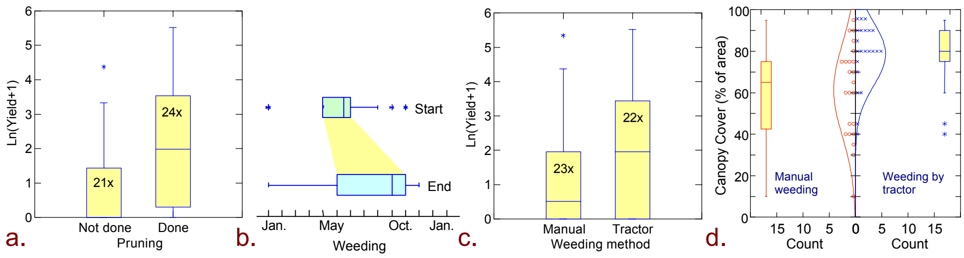

Figure 7. a: Effect of pruning on mango yields.
b: Months of weeding.
c: Effect of weeding method on mango yields.
d: Relation between canopy cover and weeding by tractor (counts, normal curves and box-plots).

Fertilization

Farmers used compound fertilizers (NPKs) anly (21x), NPKs with Farm Yard Manure (FYM; 6x), FYM only (5x) or none (13x). These amendments did not have a significant impact on yields, although NPKs appear to improve yields (**Figure 8** left). Half of the farmers that did not achieve yields did apply NPKs. Most farmers that applied NPKs (27x) applied it during the period March-July (**Figure 8** right). Two farmers applied NPKs during two separate periods. NPK application was mainly by surface broadcasting under the tree canopy (23x); four farmers practiced various forms of incorporation in the soil. Quantities applied were expressed in various units, e.g. handfuls/tree, and could not be converted to standard units. The main NPK-type used was 15-15-15.

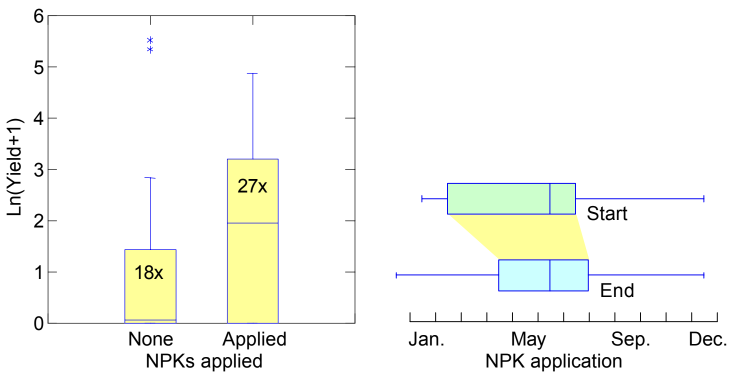

Figure 8. Impact of mineral fertilizer application on mango yields.

Incidence and Control of Pests and Diseases

All orchards suffered from stem boring caterpillars and several from beetles, flies and fruit piercing moths. Diseases affecting mango were not reported. To control caterpillars, 34 farmers used pesticides, viz. Lannate (12x), Azodrin (9x), Civin-85 (7x), Furadan (4x), Folidol (5x) and Thiodan (3x).

Regression showed that only Azodrin application had a positive moderately significant effect on yields (**Figure 9**[a]). The method of pesticide application was either by knapsack or by motor sprayer. Use of a motor sprayer had a highly significant impact on yields (Adj.-R^2 of 15.8%), which might be explained by the fact that pesticides were sprayed deep into the tree canopy. The regression equation derived is: Ln(Yield+1) = 1.17 + 1.88 (if a motor sprayer is used); see **Figure 9**[b]. Motor sprayers were almost exclusively used for application of Civin-85 (4x), and Azodrin (3x). Spraying was practiced throughout the year. Besides spraying, farmers cut branches that showed signs of caterpillar damage. Several orchards were badly damaged by this practice.

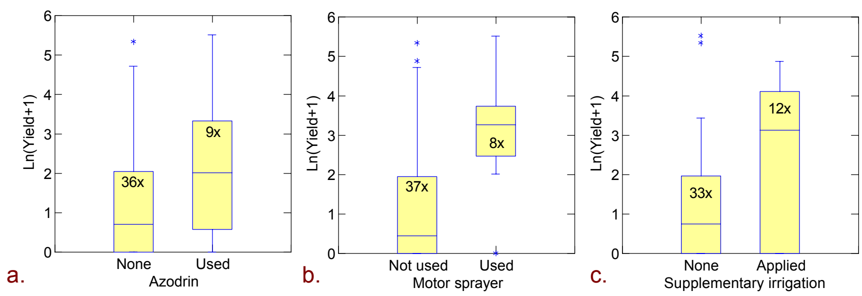

Figure 9. a: Effect of Azodrin on caterpillar control.
b: Effect of motor sprayer of pesticide efficiency.
c: Effect of supplementary irrigation on yields.

Irrigation

Eighteen farmers reported experiencing water shortage during the fruit bearing stage (end of dry season). This number includes five (out of twelve) farmers who were able to apply supplementary irrigation water when available. Note that wells etc. dry-up when irrigation water is most urgently needed. Irrigation infrastructure present within or in the direct proximity of orchards included water reservoirs / dams (8x), ground water wells (10x), canals (6x), underground irrigation pipes with taps above the surface (5x), and hose-pipes / tubes for irrigation purposes present within the orchard (7x).

Water shortage during the fruit bearing stage or the presence of irrigation structures did not visibly correlate with yields. Supplemental irrigation led to higher yields (**Figure 9**[c]) and significantly explained 7% of the overall yield variability. The equation is: Ln(Yield+1) = 1.20 + 1.17 (if ability to apply supplementary irrigation water exists).

5. Logistic regression

In section 4.1, it was discussed that a Poisson distribution denoting 'yield' (16x) versus 'no yield' (29x) can be estimated through logistic regression. The established linear prediction (LP) part of the logistic model with a probability for all coefficients below 10%, and a McFadden's Rho^2 of 62%, reads:

$$LP = 2.73 - 0.89*\mathbf{SLO} + 0.085*\mathbf{SLO}^2 - 4.20*\mathbf{TXT} - 3.35*\mathbf{TER} + 2.88*\mathbf{WHC} - 10.13*\mathbf{HPI} + 3.14*\mathbf{PRU} + 3.24*\mathbf{YEA} + 3.27*\mathbf{NPK} - 4.00*\mathbf{TRA}$$

Where:

SLO	=	Slope (%) within the orchard
TXT	=	1 if top-soil texture is LS or SL (not C, SC, or SCL)
TER	=	1 if terrain is terrace (not hill or footslope)
WHC	=	1 if reported water holding capacity (by the farmer) is poor (not fair or good)
HPI	=	1 if hose-pipes / tubes for irrigation purposes were present in the orchard (otherwise 0)
PRU	=	1 if pruning of trees is done (otherwise 0)
YEA	=	1 if relatively a good year and -1 if relatively a bad year
NPK	=	1 if mineral fertilizers applied
TRA	=	1 if weeding with a tractor (not manual)

The model's sensitivity (response prediction accuracy) is 87% and specificity (non-response prediction accuracy) is 77% (**Figure 10**). The model suggests that the probability to expect yield (assumed mechanisms for 'flower initiation' according to a "0,1" Poisson distribution) is higher if orchards are:

- situated on finer textured soils on steeper slopes located in hills and footslopes with poor water holding capacity, and
- not watered by hose-pipe, fertilized by NPK, pruned, and weeded by tractor.

Figure 10 shows that the prediction is prone to errors and that the normal distribution lines of the two groups overlap, i.e. estimates are not all zeros and ones. The model is thus not conclusive. Most likely, used independents have an indicative behavior and not necessarily a causal one.

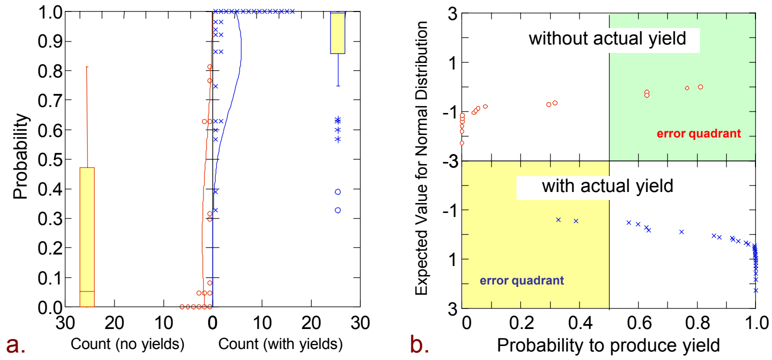

Figure 10. Group-wise comparison of logistic model results:
a: Probability to expect mango yield.
b: Z-scores of mango yield probabilities.

6. Multiple linear regression to predict Ln(Yield)

Multiple regression of the 29 sites that had positive yields resulted in a yield model with an adjusted-R^2 of 88.3%. The model reads (all coefficients with P < 3%):

Ln (Yield '000 Bath/ha) = - 2.76 + 0.44***SLO** - 0.021***SLO**^{2} + 0.78***TXT** - 1.21***TER** + 0.37***pH** + 3.10***CAN** + 0.92***TRA** + 2.05***MOT** + 0.80***PRU**

Where:

SLO	=	Slope (%) within the orchard
TXT	=	1 if top-soil texture is SCL (not LS, SL, C, or SC)
TER	=	1 if terrain is footslope (not terrace or hill)
pH	=	pH of the topsoil
CAN	=	1 if canals were present in the direct proximity of the orchard
MOT	=	1 if pest control is carried out by motor sprayer
PRU	=	1 if pruning of trees is done
TRA	=	1 if weeding with a tractor (not manual)

The equation suggests that yields improve if:

- The slope in the orchard and the pH of the topsoil are relatively high;
- The orchard is situated on Sandy Clay Loam but not on footslopes;
- Canals are present in its direct proximity;
- Management includes weeding by tractor, pest control through use of a motor sprayer and pruning.

The equation is put to use to estimate yields for 16 sites that had "0" yields (**Figure 11**[a+b]). Estimated yields of both yield categories were similarly distributed and the two drawn normal distributions are not significantly different (P of 66% that they are identical[12]). The Ln(Yield) estimates range from -2 to 6, indicating that the model predicts very low actual yields for several mango orchards. It supports that orchard yields follow a lognormal distribution and that observed "0" yields represent very low actual yields that are not commercially relevant. Results suggest also that additional parameters are needed to break the two categories down. Joint use with the logistic model will result in error propagation, i.e. the joint predictive power will be as low as 54% (62% * 88%). This low predictive power makes it attractive (to attempt) to fit a linear multiple regression model through all yield data without previous stratification (see next section).

Logistic and multiple regression models share the independent parameters "slope". In both cases steeper slopes increase the probability to obtain higher yields; in the first model the impact of slope is greatest on slopes of 10% or steeper whereas in the latter effects are greatest if slopes are from 0-5% (**Figure 11**[c]). Joint use of the models will likely nullify these effects.

[12] Kolmogorov-Smirnov Two Sample Test.

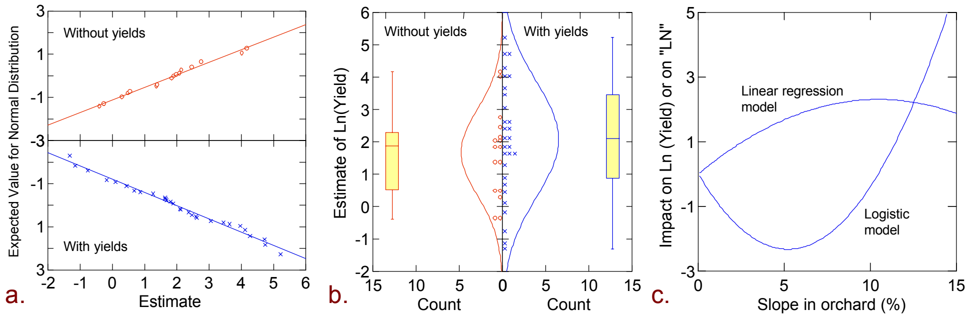

Figure 11. Regression model results based on 29 sites with positive yield data and extrapolation to sites with "0" yields":
a: Z-scores of mango yields.
b: Probability to expect a certain mango yield.
c: Impact by slope on the Linear Part (LN) of the logistic model and on the Ln(yield) estimates of the regression model.

7. Multiple linear regression to predict Ln(Yield+1)

Both presented models include terrain, texture and water holding capacity co-variables. Testing of their interactions proved useful just as the term 'canopy cover x use of a tractor for weeding' (based on **Figure 7**[d]). Use of a motor sprayer occurred only when pruning was done and the two co-variables were re-combined into 2 new ones. The 10 variables included in the provisional model explained 89% (Adjusted-R^2) of the total variability of yields (**Table 3**).

Table 3. Linear multiple regression results of Ln(Yield+1) of mango

Adjusted multiple R^2: 0.893
Cases are weighted by (% of mango trees/orchard x orchard size).

Effect	Coefficient	P(2 Tail)	R^2 when entered
Constant	-1.109	0.330	
If spraying by motor sprayer **AND** pruning done	1.139	0.000	49
Year effect (1=good, 0=normal, -1=bad)	1.165	0.000	66
If sprayed with Azodrin	1.322	0.000	73
If not in hills **AND** if poor water holding capacity	-1.845	0.000	78
If weeded by tractor **MULTIPLIED BY** canopy cover	0.008	0.004	82
If ability to apply supplementary irrigation water	0.777	0.001	85
If on footslopes	-0.398	0.076	87
pH of the top-soil	0.354	0.004	89
If poor water holding capacity	0.870	0.013	91.5
If pruning done **AND** not sprayed by motor sprayer)	0.523	0.033	92

The one-sample t test of model residuals showed that the mean of -0.40 is not significantly different from zero (P = 1.5%). The Kolmogorov-Smirnov One Sample (2-tail) Test using the Normal (-0.40,1.05) distribution suggested a probability of only 15% that the residuals are normally distributed (**Figure 12**). In spite of this low probability, the results are considered sound; only 6 orchards (see the solid line in the left graph of **Figure 12**) showed Ln(yield+1) residuals of 1.5 to 3.5 while their actual reported yields were zero.

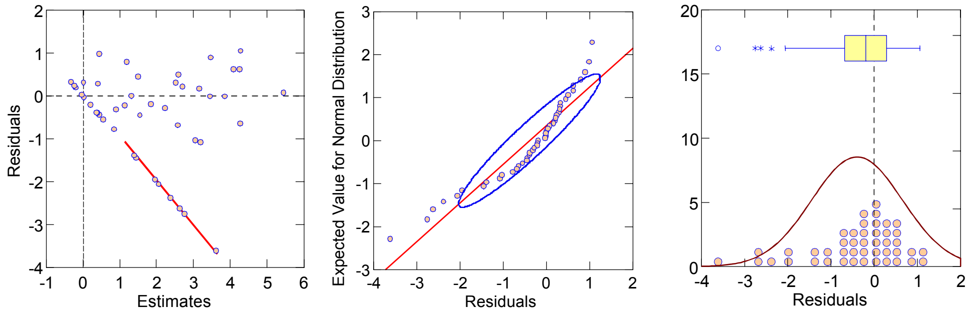

Figure 12. Normality of regression results.

The model can be written as an equation with two look-up tables:

Ln (Yield+1) in '000 Bath/ha = - 1.11 + 1.165***YEA** + 1.32***AZO** + 0.008***TRA*****CCO** + 0.78***IRR** + 0.35***pH** + **values from look-up tables**

Where:

YEA = 1 for a relatively good year and -1 for a relatively bad year
AZO = 1 if Azodrin is used as pesticide
TRA = 1 if weeding with a tractor (not manual)
CCO = Canopy cover of all trees in the orchard (%)
IRR = 1 if possible to apply supplementary irrigation water
pH = pH of the topsoil

Look-up tables:

1	Water holding capacity	
Terrain unit	**poor**	**other**
Hill	+0.87	0.00
Footslope	-1.37	-0.40
Terrace	-0.98	0.00

2	pest control by motor sprayer	
Pruning	**Not done**	**Done**
Not done	0.00	no cases
Done	+0.52	+1.14

The equation suggests that yields are higher if:

- It is not an off-year (effect by biennial bearing behavior of mango)
- The top-soil has a relatively high pH
- The orchard is situated on hills and has soils with a relatively poor water holding capacity
- The ability exists to apply supplementary irrigation water
- In fully grown orchards weeding is done by tractor
- Pruning is practiced
- Spraying of insecticides is done using a motor sprayer
- Azodrin is used to control caterpillars

Soil texture and the use of NPKs are noticeably missing in the model. Their absence is due to the already high amount of variability explained, the relatively low number of orchards with yields, and their possible correlation with included variables, e.g. the relation between texture, terrain and WHC.

8. Yield gap and yield constraints

Before evaluation of the model, interacting variables were pooled to establish their combined effect on yields. The combined effects are labeled as ‘location’ and ‘pruning + use of a motor sprayer’ (**Table 4**).

Quantification of effects by variable on yields is based on comparing the ‘best’ value that occurred amongst the 45 sites surveyed with the ‘average’ value. For instance, if 9 farmers used Azodrin, the ‘average’ value would become 9/45 or 0.2 while the ‘best’ value remains 1. The constraint specific yield gap is the difference between the two values.

Table 4. Quantified break-down of the mango yield gap by yield constraint (‘000 Bath/ha; 1993 season)

	Ln(Yield+1)						Yield	
Independents	**coeffi-cient**	**measured values**		**m. values x coeff.**		**yield gap**	**%**	**yield gap**
		avg.	**best**	**avg.**	**best**			
Constant	-1.109	1.000	1	**-1.11**	**-1.11**			
If spraying by motor sprayer AND pruning done	1.139	0.178	1	0.20	1.14			
If pruning done AND not sprayed by motor sprayer)	0.523	0.356	1	0.19	0.52			
Combined effect of 'pruning + use of a motor sprayer’				**0.39**	**1.14**	**0.75**	**13%**	**45**
If poor water holding capacity	0.870	0.289	1	0.25	0.87			
If on footslopes	-0.398	0.444	1	-0.18	-0.40			
If not in hills AND if poor water holding capacity	-1.845	0.156	0	-0.29	0.00			
Combined effect of 'location'				**-0.21**	**0.87**	**1.08**	**18%**	**65**
Year effect (1=good, 0=avg., -1=bad)	1.165	-0.067	1	-0.08	1.17	**1.24**	**21%**	**74**
If sprayed with Azodrin	1.322	0.200	1	0.26	1.32	**1.06**	**18%**	**63**
If weeded by tractor MULTIPLIED BY canopy cover (%)	0.008	38.44	95	0.31	0.76	**0.45**	**8%**	**27**
If ability to apply supplementary irrigation water	0.777	0.267	1	0.21	0.78	**0.57**	**10%**	**34**
pH of the top-soil	0.354	6.000	8	2.12	2.83	**0.71**	**12%**	**42**
Ln(Yield+1):				**1.89**		**5.86**		
Estimated yield '000 Bath/ha:				**6**		**351**		
Actual yield '000 Bath/ha:				**23**	**250**	**227**		
Sum:							**100%**	**351**

Environmental factors (location and pH) in the model explain 30% of the yield gap, management factors 49% and the year effect (species attribute) 21%. The total estimated yield gap (best-average) follows from an Ln(Yield+1) value of 5.86, which translates to an actual yield of 351 (‘000 Bath/ha). This amount is used to re-calculate the relative contribution of each variable to the overall yield gap in non-logarithmic terms. A review of identified yield constraints follows hereafter. The loglinear behavior of the yield data results in exponential yield increments for each partial yield gap closed. Thus, constraints cannot be ranked (**Table 4**, **Figure 12**). A consequence is also that management of the studied mango orchards must strive for the highest level of technology available. Interaction effects between technology aspects implemented outweigh each individual contribution. The present management is at a level that is not yet restrained by the law of “diminishing returns”.

LOCATION AND WATER MANAGEMENT

There is clearly a relation between terrain specifications and the water holding capacity (WHC) of soils. Mango requires a drought (dormancy) period for flower initiation. Subhadrabandhu (1986) noted that vegetative growth must have ceased and newly developed shoots must have reached “maturity” before flower buds are initiated. A shallow ground water table and/or a sufficient water storage (roots go down to six meters depth; Purseglove 1977) voids the impacts of a dry season. Such soils are clearly not suitable for mango orchards. Soils in hills with a poor WHC are less affected by this problem.

Young orchards and fully-grown crops that have a growth flush require proper water management. Supplementary irrigation facilities and specialized skills to assess by orchard when to apply water are a precondition for good growth. The average precipitation in Phrao is 1171 mm/year; the optimum mean annual rainfall for mango is indicated as 1500-2000mm (FAO 1992[b]). Orchards on terraces with soils of poor WHC clearly suffered from water stress during flushes and fruit bearing. The lack of water at periods when it is most needed make these soils less fit for orchard establishment.

PH OF THE TOP-SOIL

Literature suggests optimum soil pH ranges for mango of 5.0-7.0 (FAO 1992[b]), 5.5-7.5 (Purseglove 1977), and 5.5-6.5 (DLD 1989). This study identifies a positive relation between mango yields and soil pH, suggesting that near-neutral (up to 8.0) pH levels are most suitable for mango.

YEAR EFFECT, PRUNING AND WEEDING BY TRACTOR

Purseglove (1977) reports that climate influences biennial bearing and that a high soil C/N ratio is conductive to flower initiation, as is the abundant production of new growth during a proceeding ‘off’ year. Use of fertilizers during flower initiation should be avoided (Sauco 1989). Use of growth regulators may induce flowering. Tongumpai *et al*. (1989) reported successful use of ‘Cultar’ (paclobutrazol; inhibits gibberellin biosynthesis), applied as ‘collar drench’ to several mango varieties in Thailand. All cv’s flowered intensely 3-5 months after the treatment, whereas untreated trees did not flower at all. Cv’s that flower with difficulty may also need a

bud-dormancy breaking agent, e.g. potassium nitrate (as a spray). The technology was successfully used to produce off-season fruit at high gross-margins.
Pruning of mango trees is not common, but practiced in Phrao to remove branches that are affected by stemboring caterpillars. Pending on its timing, pruning induces a new growth flush, and possibly fruits the year after.

Weeding by tractor is a management aspect that indirectly seems to influence the hormonal balance of trees. Weeding by tractor is done by ploughing-in the weeds and results in cutting sub-surface mango roots; it must thus be labeled as root-pruning. This practice restricts water and nutrient uptake and if done at the appropriate time in the tree's physiological cycle, results in more prolific flowering and better yields (Subhadrabandhu 1990, Sauco 1989).

SPRAYING PESTICIDES

In Thailand, the price of pesticides is high so that most growers cannot afford adequate pest control (Polprasid 1986). Only Azodrin (monocrotophos) proved effective, even when not applied by motor sprayer. The high efficiency of motor sprayers to apply pesticides into the canopy is proven beyond doubt.

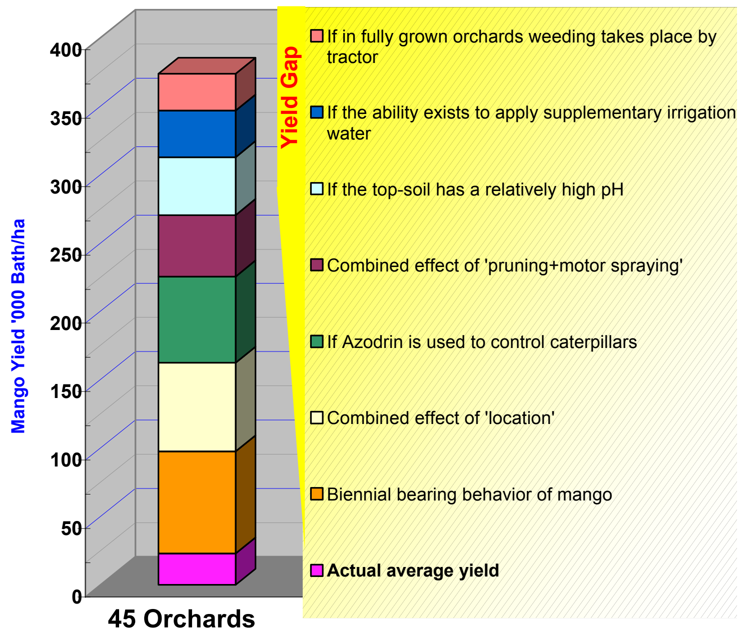

Figure 13. Yield constraints of mango orchards in Phrao (1993 season).

The specialized management requirements of mango orchards require not only a high level of knowledge and experience by farmers but also a well-informed extension service. Close(r) collaboration between this service and researchers of universities and research stations is strongly recommended.

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