CHAPTER 6

Bayesian Belief Network Model

6.1 Surveys and Interviews with Farmers

A questionnaire was designed for the interviewing process with longan grower. The original draft was used for the first five interviews, and afterward, an improved version was used for the remainder of the interviews. The questionnaire had 3 parts:

1. General information, such as name, number of people in family, number of laborers on farm, and size of farmland(s).
2. Production of longan, such as type of longan trees in orchard(s), planting spacing, soil properties, number of trees in orchard(s), age of orchard(s), and fruit production yield.
3. Details of longan production features and management, such as branch trimming, fertilizing, the use of hormones, use of herbicides, use of pesticides, watering system(s), flowering stage, fruit-setting stage, and harvesting stage. Each of these stages in the tree's development is asked about in detail for year cycle.

All of the information from these 150 interviews with famers was collected and put into a Microsoft Excel worksheet. This database was specifically about longan production in Phrao District in the Province of Chiang Mai. This database was also a factor in the development of the BBN model, which works to estimate the output of longan fruits.

The information from these interviews was analyzed using the descriptive statistics. The farmers' answers were grouped into the following three categories:

1. Characteristics of longan trees, such as species, age, tree spacing, and trimming. All of these variables affect the tree's characteristics as well as the size and shape of its canopy.

2. Physical characteristics of the land used for longan production, such as temperature, rainfall, soil, and fertility.
3. The management of fertilizers, herbicides, pesticides, watering systems, and hormones.

This information was analyzed in order to find the data distribution as described in further detail in the next section.

6.1.1 Physical Characteristics of Longan Trees

6.1.1.1 Planting spacing

There was a variety of tree spacing distances implemented. The distance depended on several factors: the farmer's intention, his management style, and the physical landscape. The range was anywhere between 3x3 to 15x15 meters. Most orchards had a planting space of 8x8 meters. Specific factors in deciding the tree spacing are the level of the soil fertility, the size of the trees canopies, and the plan for managing the trees.

Out of the 150 interviews, three groups of answers emerged. The narrow group consists of 3x3 to 5x5 meters. This group represents 34% of the total. The moderate group has planting spacing from 6x6 to 8x8 meters, representing 59% of the total. The wide group consists of anything more than 8x8 meters. This group only takes up 7% of the total (Figure 37).

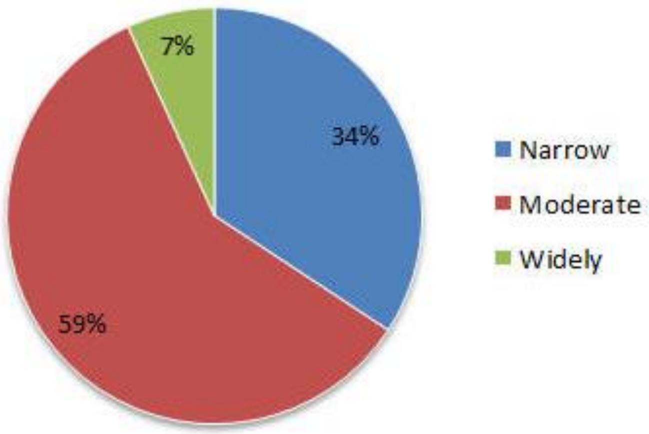


Figure 37 Distribution of tree spacing in the research field.

6.1.1.2 Species

All of the longan grower in the research field plant “Daw” variety. This variety bears its fruit earier than other varieties, and the fruit is bigger than average with a big seed and a moderate amount of flesh. The flesh is in a mixture of white and yellow. The fruit of this variety smells good and tastes sweet. The tree grows rapidly and constantly produces fruits.

6.1.1.3 Branch trimming

Branch trimming leads to healthy trees which produce larger yields of high-quality fruit. Once the harvest season is over, the trees must be prepared again by trimming their branches. It is also good for protection against diseases and pests. When trimming, farmers usually cut one or two branches nearest to the middle of the canopy. This allows sunlight to get through canopy easily and thereby creates higher photosynthesis efficiency.

Some of the farmers interviewed did not trim their trees at all. Those who did cut branches used several different tools, such as knives, saws, chainsaws, and clippers. The number of laborers employed for the job was about the same for every farmer. All of the farmers had similar reasons for trimming trees in their trees if they did, such as to allow sunlight through the canopies. However, there was a difference when it came to when the farmers trimmed. Seventy percent cut branches sometime between August and October, while 15% chose sometime between November and January, and 12% cut between February and April. Only 3% trimmed during the period between May and July (Figure 38).

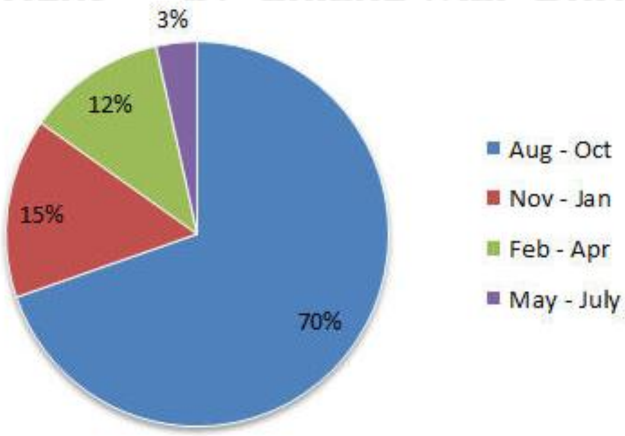


Figure 38 Distribution of when farmers trim their trees.

The farmers were asked about what shape they preferred to trim their trees. There were two main answers: uniform and non-uniform. While 62% of the farmers preferred a uniform trimming, either in the shape of a half circle or oval, because it is believed that these shapes produce the highest yield in orchards; the remaining 38% preferred a non-uniform trimming (Figure 39).

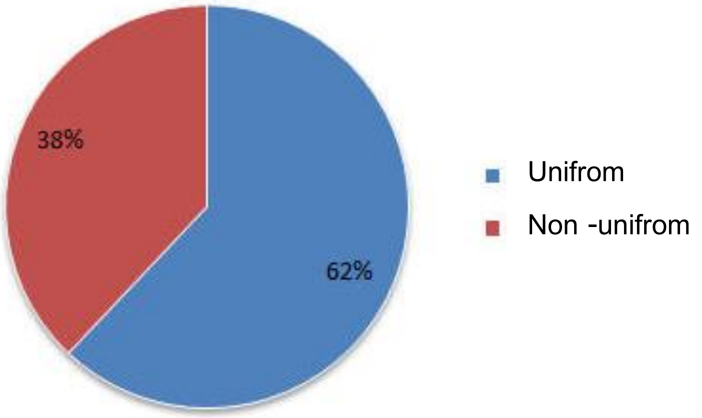


Figure 39 Distribution of the shape preference in branch trimming.

6.1.1.4 Size of the canopy

The size of the canopy affects the flowering performance of the tree, which in turn affects the yield of fruits. Another factor in longan fruit production is the age of the tree. Trees aged 1 to 3 years old have not yet been produced fruit. Their canopies should be trimmed in a circular shape in order to encourage growth. Trees aged 4 to 5 years old have started to produce fruits, so their branches should be trimmed after harvest for the reasons mentioned and with the method of cutting 1 or 2 branches near the middle to allow a vertical space for sunlight. Trees aged 5 to 10 years old should have their canopies trimmed after harvest to prevent their canopies from overlapping as well as for the same reasons as younger trees. Trees at this age should also be trimmed at the top to maintain a maximum height of no more than 3 meters.

When the farmers were asked how many branches and leaves they trimmed off the trees each season, 61% said they cut less than 30% of the branches, while 34% estimated that they cut somewhere between 30 and 50%, and 5% said they trimmed a lot—about 60 to 90% (Figure 40).

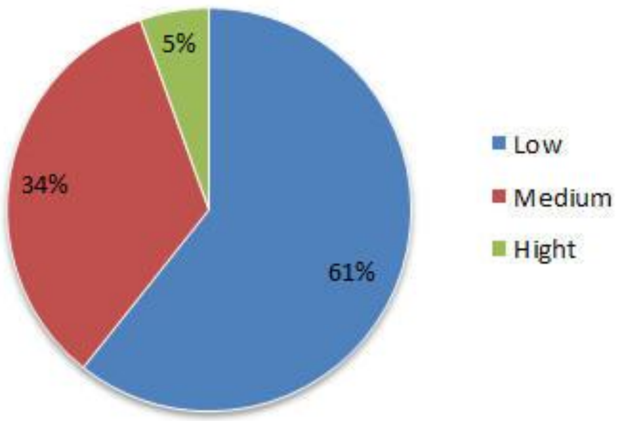


Figure 40 Distribution of the percentage of branches cut off at different extent.

6.1.1.5 Age of the trees

From the interviews, it was learned that 54% of the farmers possessed trees ranging from 6 to 12 years old. Totally 35% of the farmers had trees between 13 and 20 years old, and orchards of trees between 0 to 5 years old and 20 to 30 years old were owned by 5% and 6% of farmers respectively (Figure 41).

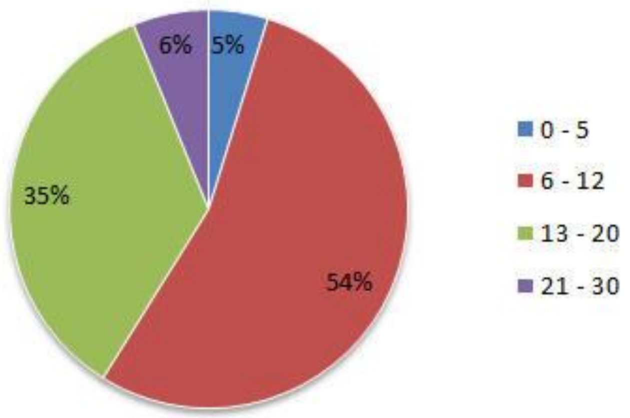


Figure 41 Distribution of trees in different age groups.

6.1.1.6 Total area of longan fruit in canopy

From the process of analyzing the longan fruit areas in the photos, it was discovered that the total fruit area within the canopy determines the yield at harvest time. From the results of the 30 chosen farms, normalized classification was used to rate each orchard between 0 and 1. From these ratings, the farms were separated into four groups based on their ratings. The first group had a rating of 0 – 0.25 (bad), the second group had a rating of 0.25 - 0.50 (moderately good), the third group was 0.50 – 0.75

(good), and the fourth group had the highest rating at 0.75 – 1 (very good). Each of the first three groups has roughly the same number of farms in it as the others (around 28 - 29%). The fourth group only has 14% out of the total number of farms (Figure 42).

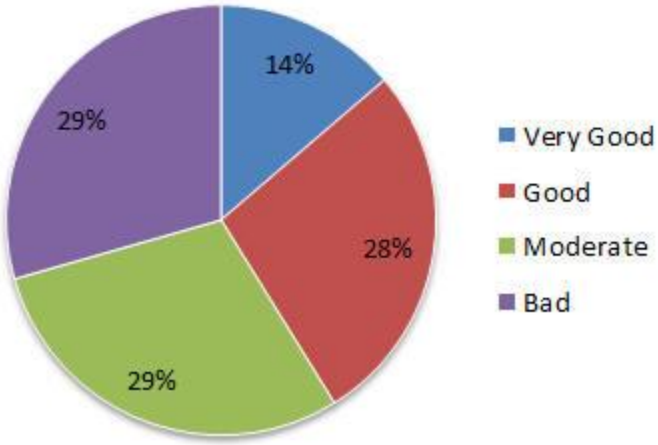


Figure 42 Distribution of the total fruit area in the canopy before harvest time.

6.1.1.7 Longan yield (kg/rai)

From the interviews with farmers concerning their longan fruit yield, it was learned that the average yield in a single orchard is 744 kg/rai. The orchard which yielded the least had 100 kg/rai, and the orchard with the highest yield produced 2,500 kg/rai. These results mean that 49% of the surveyed farms had a yield between 500 – 1,000 kg/rai (moderate yield level), 31% had a yield between 200 – 500 kg/rai (low), 14% had a high yield of 1,000 – 1,500 kg/rai, 1% had a very high yield of 1,500 – 2,500 kg/rai, and another 5% had a yield very low of 0 – 200 kg/rai (Figure 43).

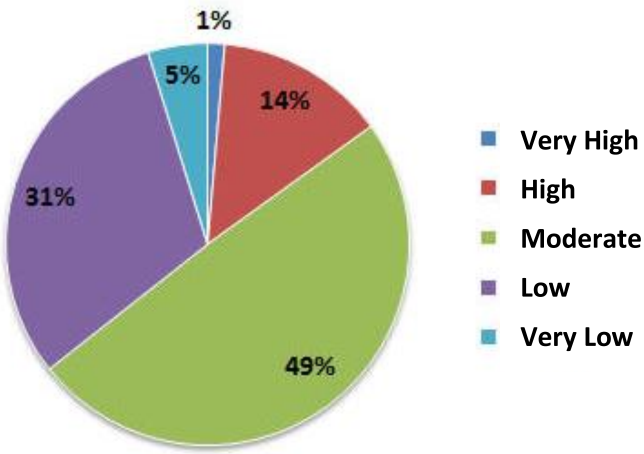


Figure 43 Distribution of the longan fruit yield level in the target areas.

6.1.2 Physical Characteristics of the Land

6.1.2.1 Temperature

Temperature is an important factor for boosting longan yield, especially right before the flowering stage (Dec. – Jan.). This study looked at the temperature records for the past 25 years for Phrao District, and the conclusion was that the temperature is uniform throughout the area of study. On average, the temperature maxes at 29 degrees Celsius and its minimum is at 13 degrees Celsius between December and February.

6.1.2.2 Watering systems

Longan grower water their trees in a variety of ways. Their answers were grouped into four categories. 40% of farmers rely solely on rainfall, 26% use some form of irrigation system(s), 11% use sources of groundwater, and 23% have access to bodies of water (surface water) (Figure 44).

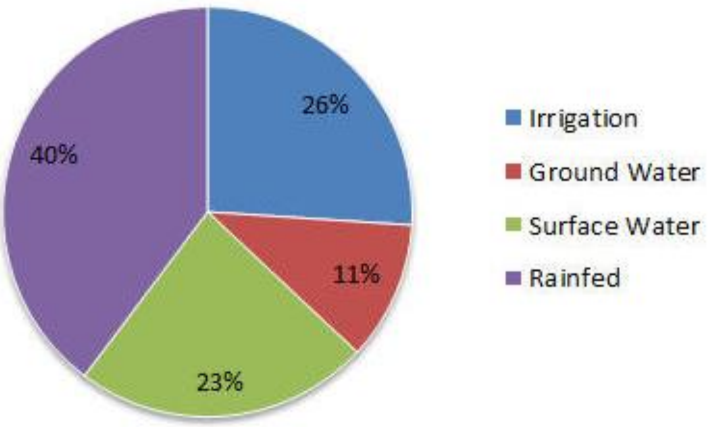


Figure 44 Distribution of watering systems.

6.1.2.3 Soil fertility

This study required access to information concerning the quality of the soil in the research field. The information was obtained by looking at the records at the Land Development Department. According to their database and the opinions of the farmers, the lands used for longan orchards are in the following conditions: 39% of the farmers have rich, loose soil filled with organic matter, 33% have soil of medium quality mostly clay; with high density, while 28% work with low-quality soil, which is either sandy or rocky and has a low amount of organic matter (Figure 45).

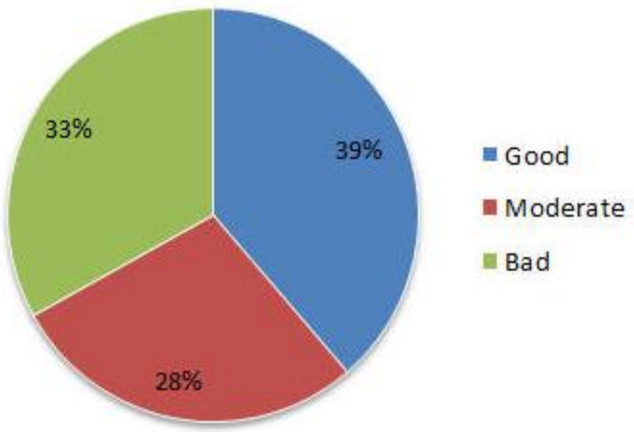


Figure 45 Distribution of Soil fertility condition at orchard sites.

6.1.2.4 Longan Trees' Health

Determined from the interviews with the farmers, their trees' health was rated as good, moderate, or low. It can be concluded that 71% of the trees had good health, 18% were moderately healthy, and 11% had low health (Figure 46).

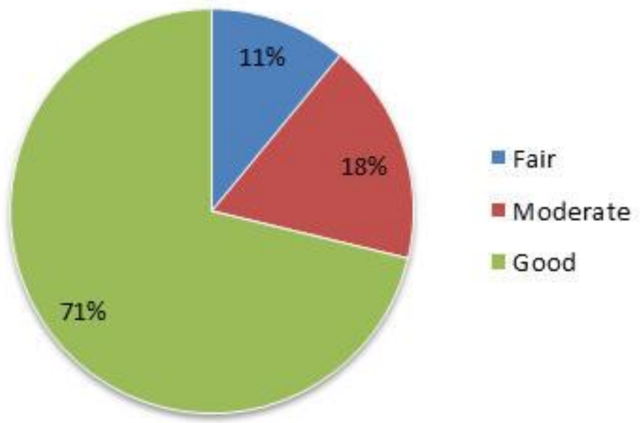


Figure 46 Distribution of longan orchards in different condition of horticultural health.

6.1.3 Cultural Practices

6.1.3.1 Use of fertilizers

When asked about the types of fertilizer they use (chemical or organic), the amount they use, and the duration of their use throughout the season, 76% of the famers said they use fertilizers in low amounts (0 – 100 kg/rai), 14% use 100 to 200 kg/rai, 5% use a high amount of 200 to 300 kg/rai, and another 5% use the highest amount of 300 to 500 kg/rai (Figure 47).

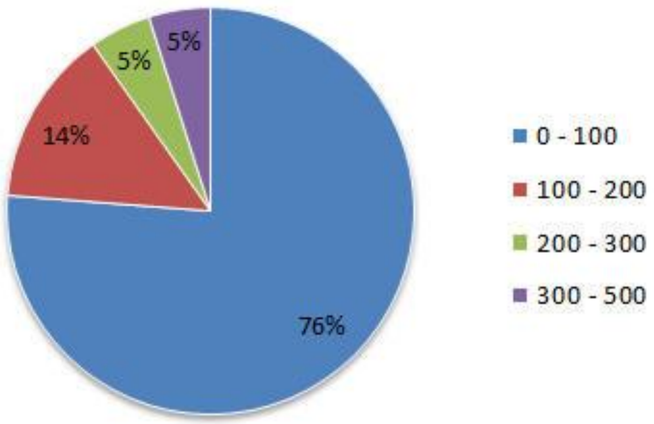


Figure 47 Distribution of applying different rates of fertilizer in kg/rai.

6.1.3.2 The amount of water used

It is very important for farmers to have plenty of water to irrigate their orchards, especially considering years in which there are droughts. Watering doesn't begin until after the flowering stage. In the first week, longan trees should be watered a little bit at their branches and around their base; but not too much, so that the trees can adjust to the introduction of water. In week 2, there should be a significant increase in water given. For trees with a canopy of 7 meters in diameter, they should be watered 200 – 300 ml. for two times a week.

The farmers were asked about how many times they water their orchards each year, and 68% of them answered that they water their trees no more than 3 times a year, while 20% water their trees between 3 to 6 times a year, and 4% water their trees 7 to 9 times each year (Figure 48).

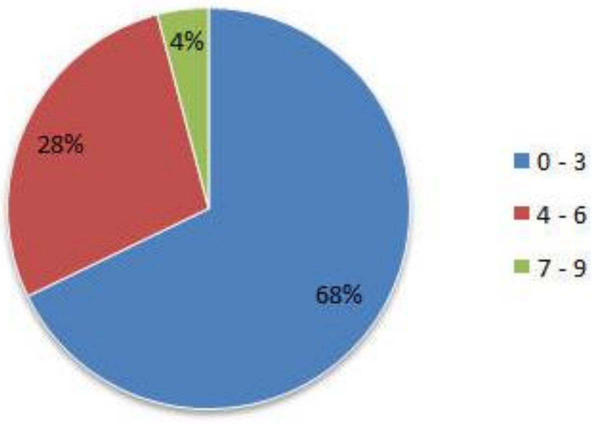


Figure 48 Distribution of the number of times per year that the trees are watered.

6.1.3.3 Use of herbicides and pesticides

The farmers were asked about what types of herbicides and pesticides they use and how much they use throughout the farming season. Five percent of the farmers interviewed did not use any form or amount of herbicides and pesticides; while 49% used both, 36% used pesticides but used other means besides chemicals to kill the weeds and other unwanted plant life, and 10% used herbicides but not pesticides (Figure 49).

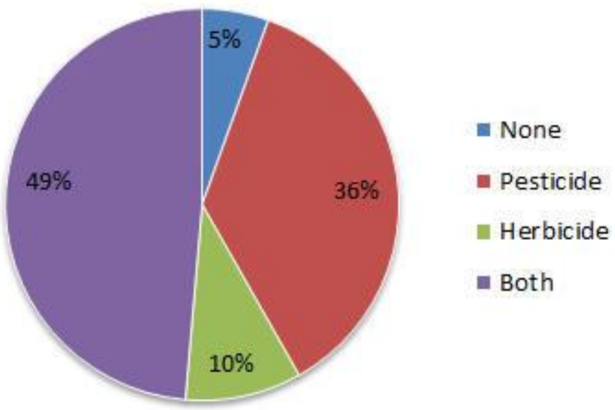


Figure 49 Distribution of grower's use of herbicides and pesticides.

6.1.3.4 The number of activity

It was learned from the longan farmers that they have a variety of methods for taking care of their orchards. Taking care of the trees includes the use of fertilizers, the use of herbicides and pesticides, branch trimming, and watering schedules. The following data involve the number of times a farmer performed at least one of the tasks mentioned above to shows how well grower are managing their orchards. Apparently, 63% of the farmers interacted with their orchards no more than 20 times per year. This is considered a small amount of time spent on caring for the trees. Meanwhile 28% took care of their trees somewhere between 20 and 30 times each year, and 8% tended their orchards a lot more times than that throughout the year. There were also 1% of farmers who looked after their trees hardly at all (Figure 50).

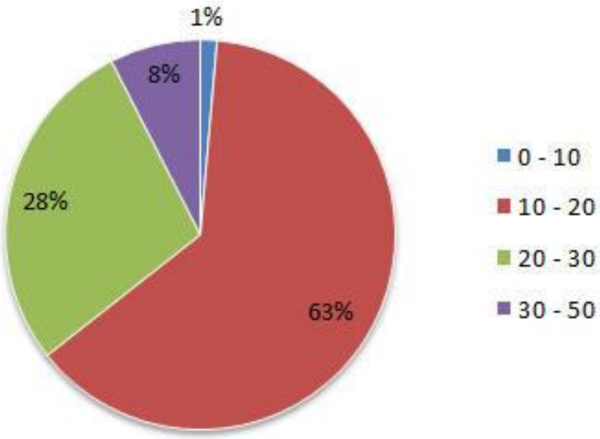


Figure 50 The number of times per year farmers tending their orchards

6.1.3.5 Flower induction

The farmers were asked about whether or not they have ever used substances containing flowering triggering agents. In response, the farmers said they normally used potassium chlorate ($KClO_3$) and ethephon. Specifically, 53% use only ethephon, and 7% use only potassium chlorate, 25% use both, and 15% don't use any substance to encourage flowering in their trees (Figure 51).

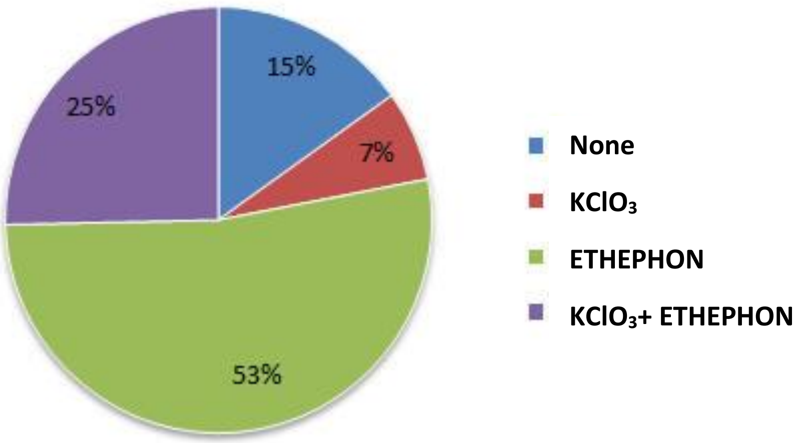
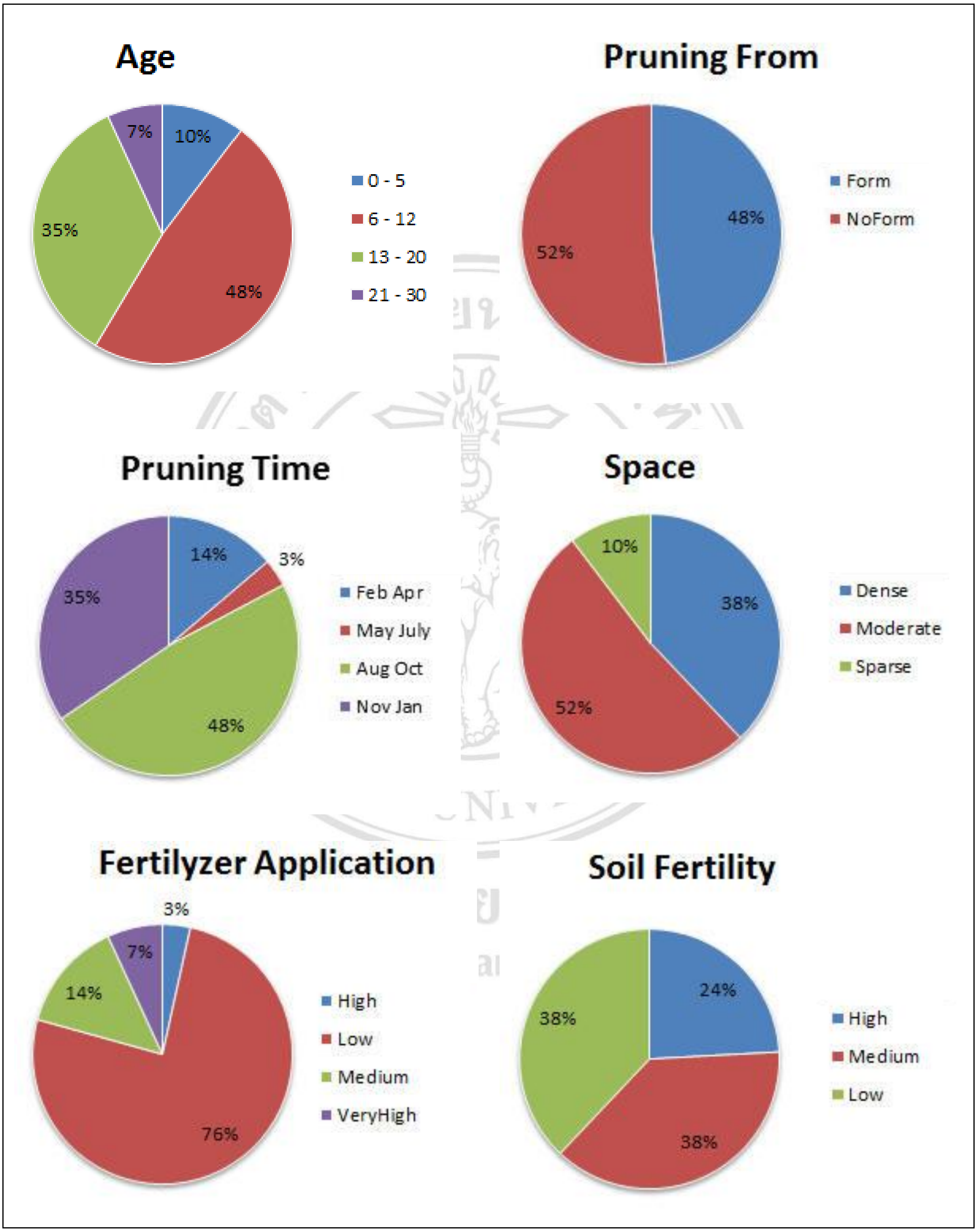
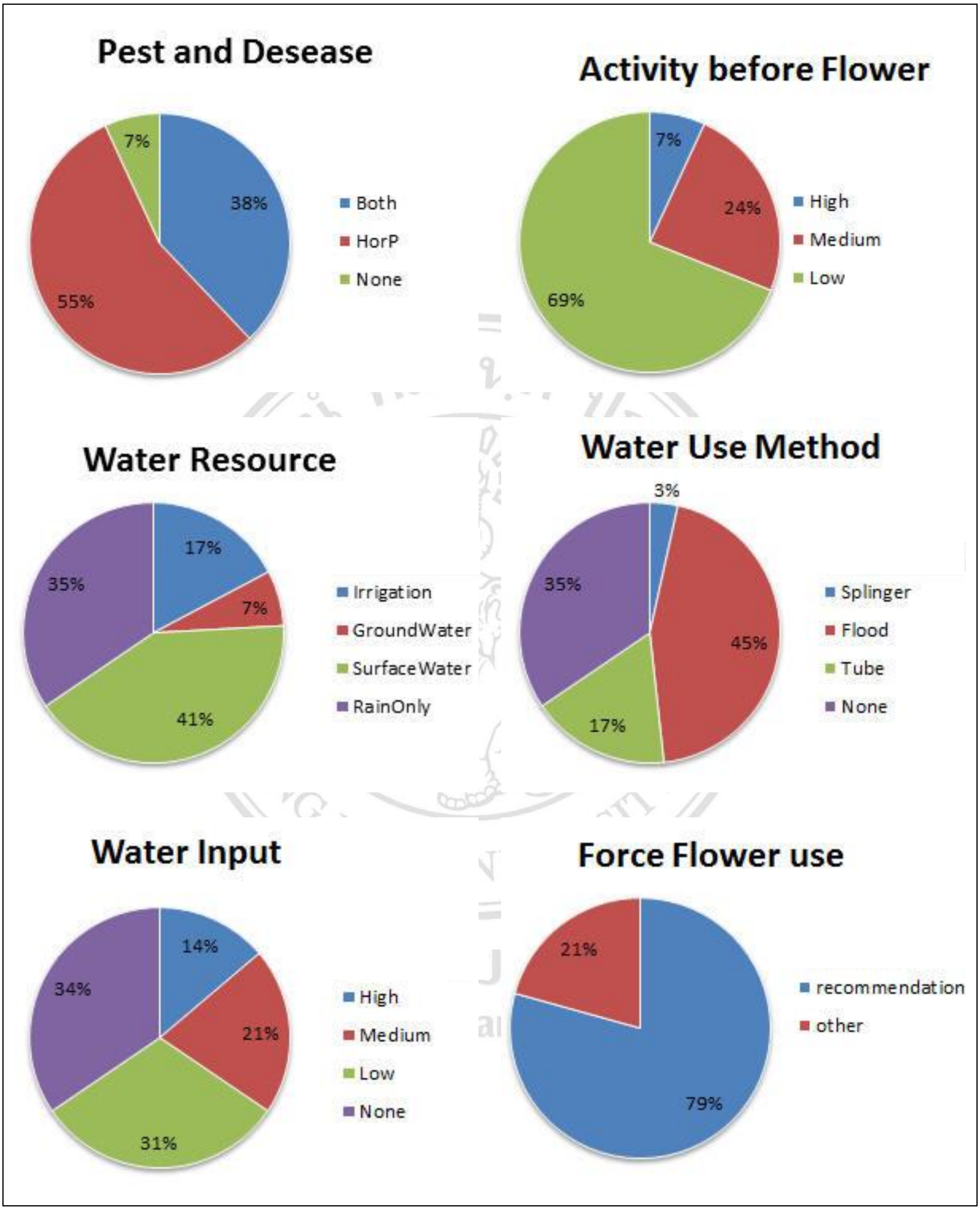


Figure 51 Distribution of the use of chemicals containing florigen.

As for the other samples in this study, there were 30 samples which were used to gather information from, for such purposes as taking photos, filling out questionnaires, and gathering data first-hand concerning the yield at harvest time. Figure 52 displays distribution of longan production from 30 samples.


Age
10%
48%
35%
7%
0 - 5
6 - 12
13 - 20
21 - 30
Pruning From
48%
52%
Form
NoForm
Pruning Time
14%
3%
48%
35%
Feb Apr
May July
Aug Oct
Nov Jan
Space
38%
52%
10%
Dense
Moderate
Sparse
Fertilyzer Application
3%
76%
14%
7%
High
Low
Medium
VeryHigh
Soil Fertility
24%
38%
38%
High
Medium
Low


Pest and Desease
7%
38%
55%
Both
HorP
None
Activity before Flower
7%
24%
69%
High
Medium
Low
Water Resource
17%
7%
35%
41%
Irrigation
GroundWater
SurfaceWater
RainOnly
Water Use Method
3%
35%
45%
17%
Splinger
Flood
Tube
None
Water Input
14%
34%
21%
31%
High
Medium
Low
None
Force Flower use
21%
79%
recommendation
other

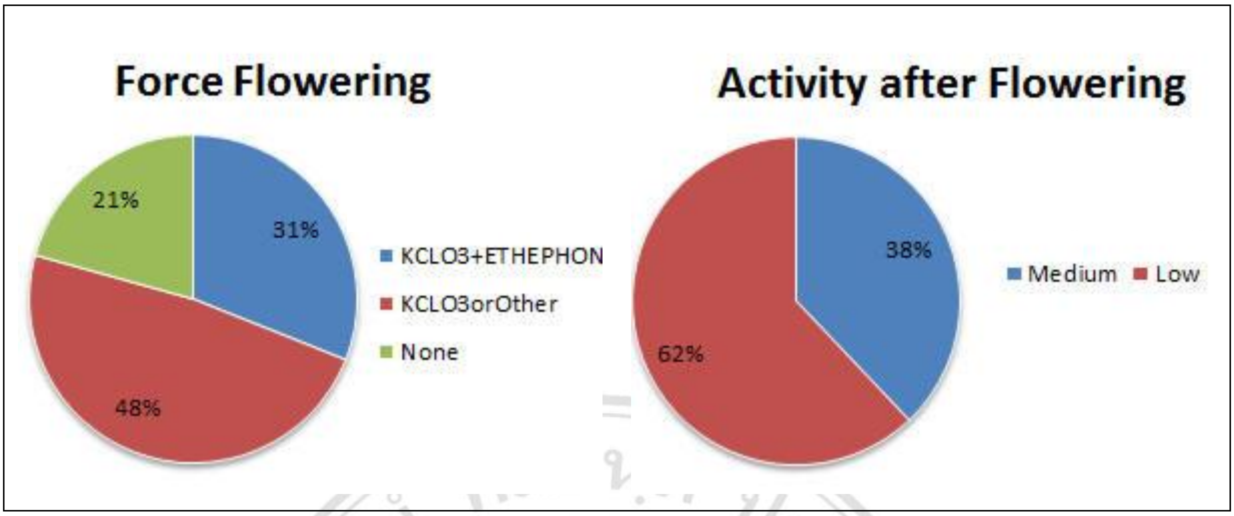


Figure 52 Information on 30 sampled farms.

The results from all of these factors were used in creating the BBN model for estimating the longan fruit yield.

6.2 Flow of Factors Impacting to Longan Yield

All of the factors used in creating the BBN model can be grouped into 3 categories of influence.

1. The physical characteristics of longan trees, such as species, age, tree spacing, and branch trimming. All of these factors determine the shape and size of the trees' canopies. This in turn directly affects the longan fruit yield.
2. The physical characteristics of the land; that is, the factors which affect the growth of the longan trees. These factors include the amount of watering, the use of herbicides and pesticides, the use of fertilizers, and the fertility of the soil. These factors affect longan trees' ability to bear fruits, which directly affects the output level at harvest time.
3. Factors which affect the flowering stage, such as temperature during the time period between November and January, the use of chemicals that induce flowering and the amount of fruits in the canopy before harvest time.

When all three categories of factors were brought together in the BBN flowchart, they created a network of information which predicted the yield of longan fruits within the target areas (Figure 53).

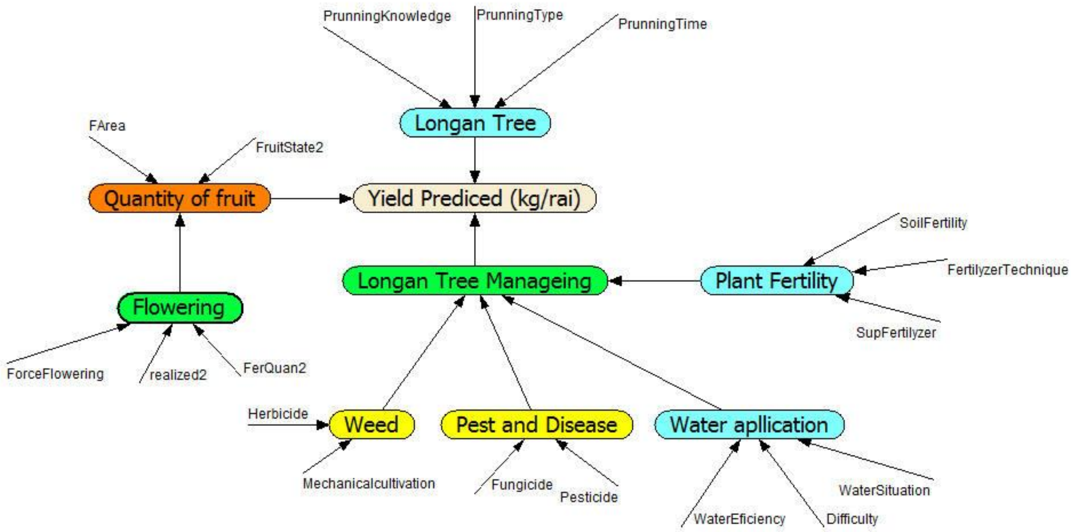


Figure 53 Relationships among all of the factors that affect longan fruit yield.

The BBN flowchart takes into account all of the information learned from the interviewed farmers concerning their expertise on managing longan orchards and from the personal observations made in the research field for this study. The Netica program was used in order to create the BBN model. Once it was finished, it was presented to experts in order to have them check its effectiveness in forecasting longan yields and make improvements to it as needed.

6.2.1 Flow Analysis and Longan Yield Model Using BBN

All of the information collected was analyzed and put into a database so that the conditional probability of each factor could be calculated.

From the first category of factors (the physical characteristics of longan trees), it was determined that the shape of the canopy directly affects the yield of fruits. The shape of the canopy depends on branch trimming, tree spacing, and the age of the tree. These factors and their relationships with one another are shown in Figure 54.

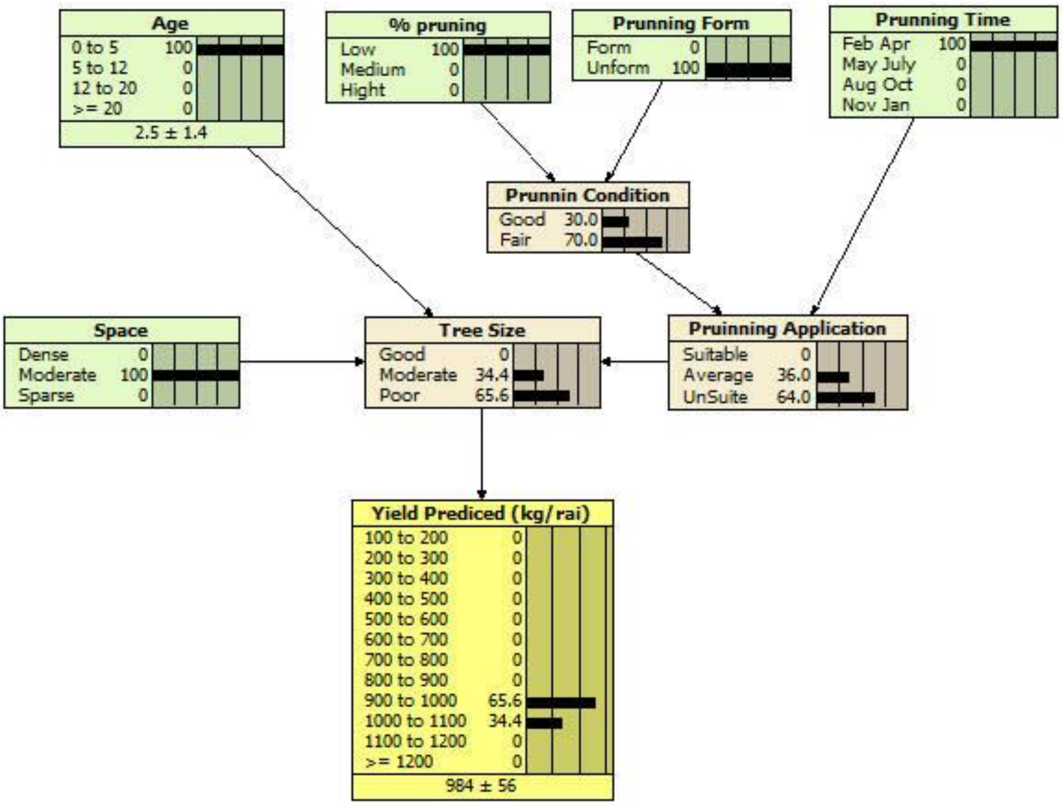


Figure 54 Physical characteristics of longan trees which affect the fruit yield.

From the second category of factors (the physical characteristics of the land), it was determined that the health of the tree directly affects the flowering and fruit-setting stages. The cultural practice factors in this category are in two groups: the management of the land, such as soil, fertilizer, diseases, and pests, and the management of water, such as the amount of rainfall, the type of watering, and the frequency of watering. These factors and their relationships with one another are shown in Figure 55.

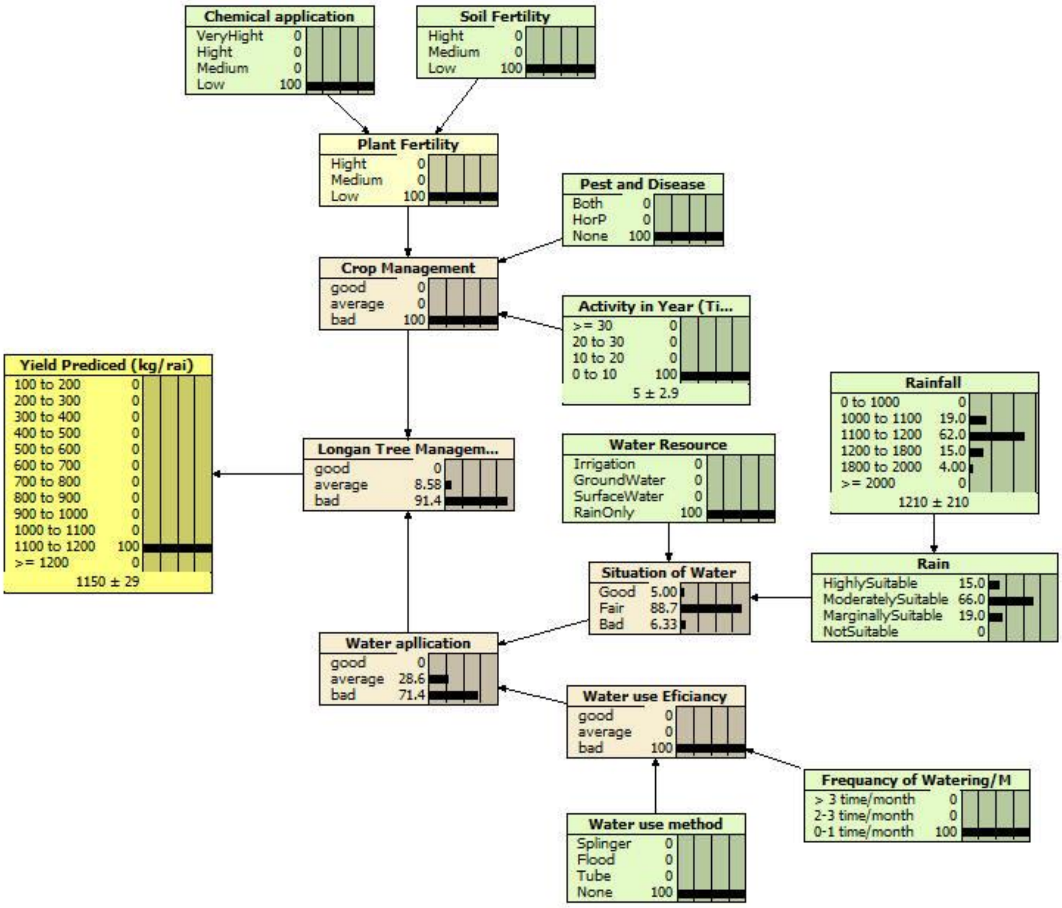


Figure 55 Characteristics of the land and management which affect the fruit yield.

From the third category of factors (those that affect the flowering stage), it was determined that the right temperature at the proper time directly affects the flowering stage. Longan trees require cold temperatures for long period of time if they are to bloom healthily. This period of time occurs from the month of November to January. The temperature needs to be from 10 – 20 degrees Celsius for a period of four weeks (Pawin el al., 2004). During that period of time, many farmers aid in the flowering process by introducing chemicals, specifically potassium chlorate ($KClO_3$). This chemical is used to induce longan flower and hence, yield for in and out of season.

Once the flowering stage ends and the fruit-setting stage begins, it is another four months until harvest time. During those four months, there are other factors which can affect the yield of fruits. For example, if the weather is too hot or there is a drought, the yield tends to below. In this study, the canopies were photographed one month before harvest time so that their total yield could be predicted through this study's calculation process. These calculations are some of the most important factors in this entire process. The numbers which were inserted into the flowchart affect everything (Figure 56).

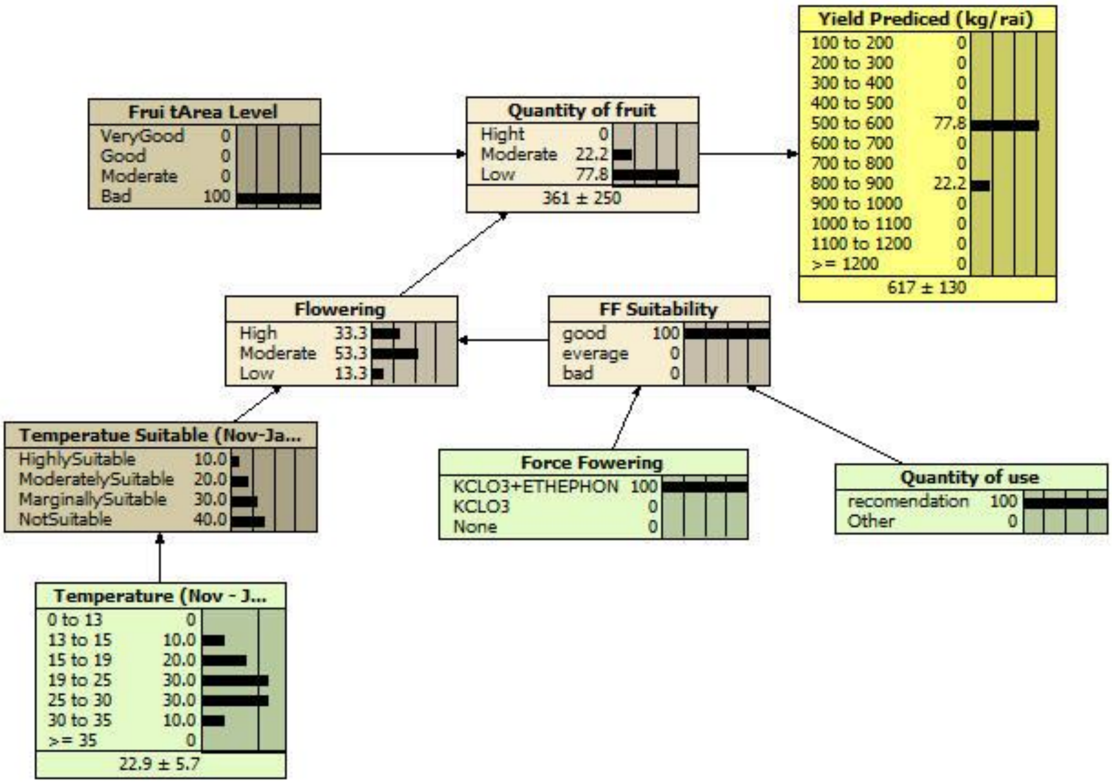


Figure 56 The relationship between weather and tree management during the flowering and fruit-setting stages.

When all 3 categories of factors were combined together, the BBN model flowchart was created. It can assess longan fruit yield (Figure 57).

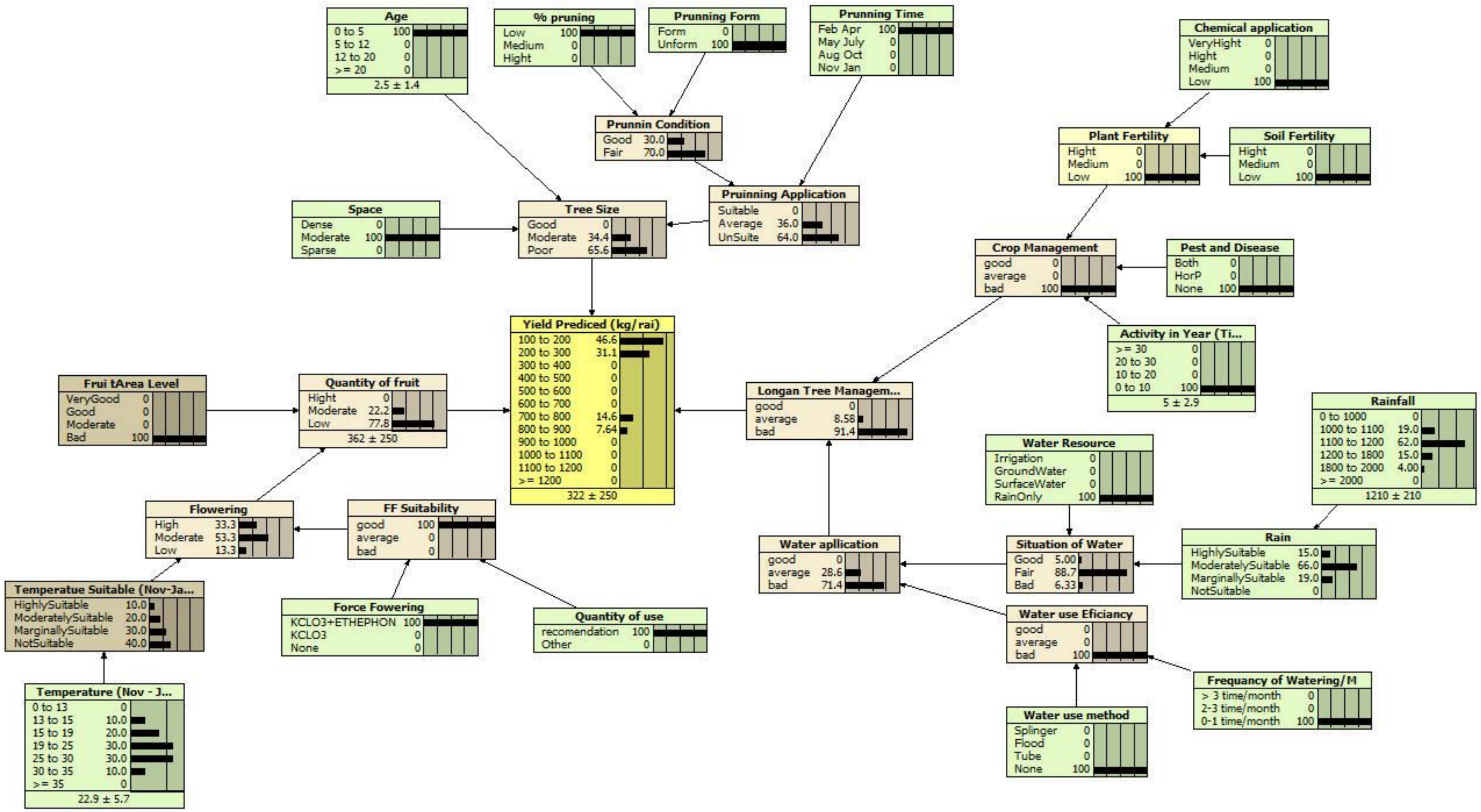


Figure 57 The BBN model used to assess longan yield.

After the experts had helped analyze the BBN model and flowchart (which includes the information learned from the interviews with the 150 farmers), it was time to test it out with actual data input. The following flowchart in Figure 58 shows the results of that test.

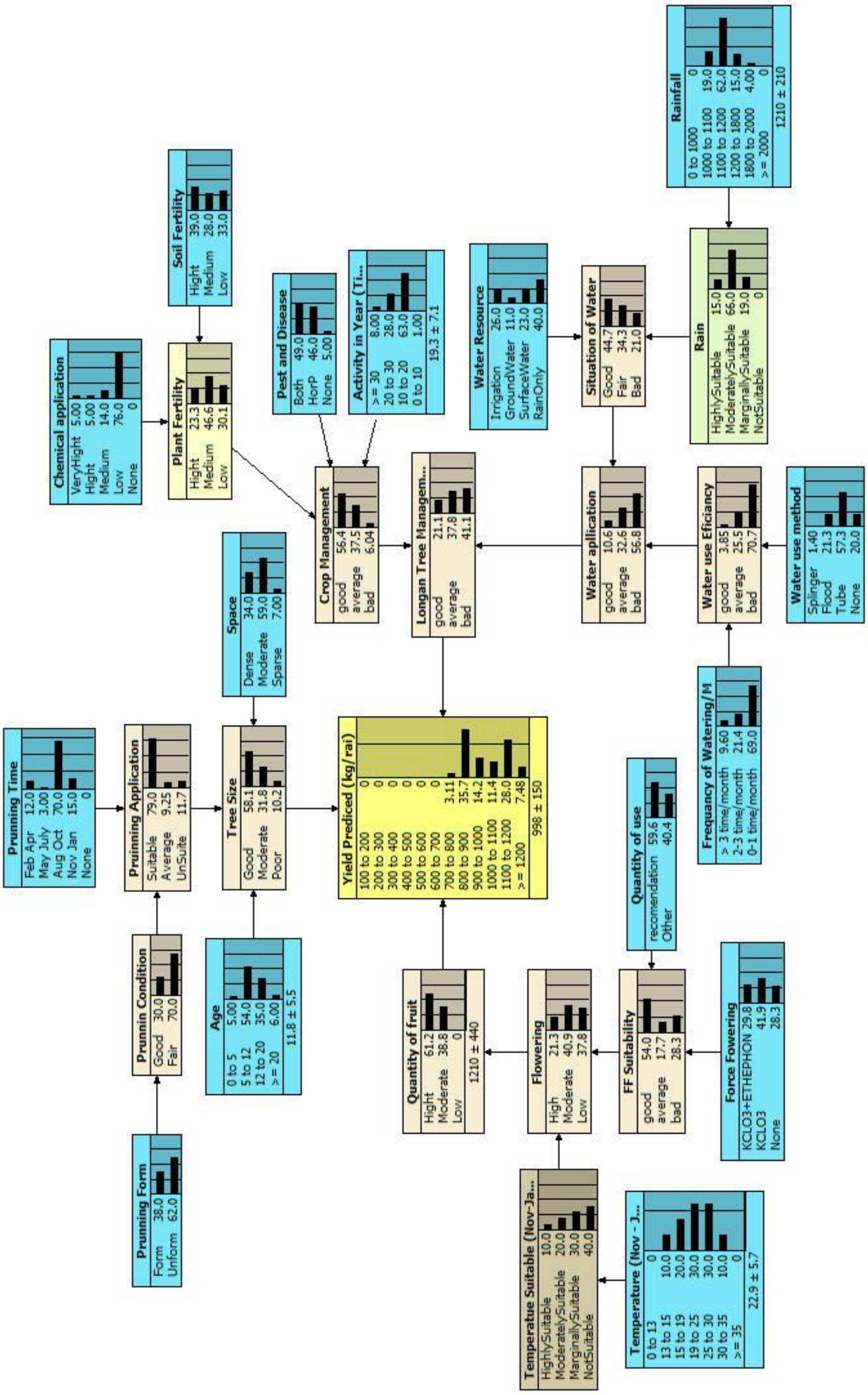


Figure 58 The BBN model used for longan yield prediction.

6.2.2 Conditional Probability Tables (CPT)

The conditional probability (CP) of the relationships between the nodes comes from the farmers' knowledge as expressed during their focus group discussion and from the questionnaire which specifically asked for their opinions on this topic. All collected information was put into CPTs by using the methods of linear summation and rescaling.

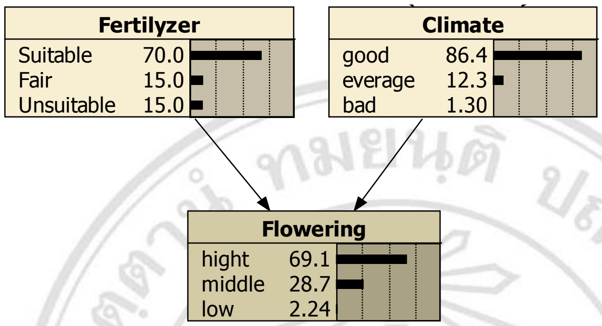


Figure 59 A sample of the relationship between parent and child nodes.

As seen in Figure 59, the parent node "Climate" has three states of probability: good, average, and bad. These three states are given a score from 1 to 5 based on how much they positively affect the child node "Flowering," where 1 is the least positive and 5 is the most positive. So the "good" state has a value of 5, the "average" state has a value of 3, and the "bad" state has a value of 1.

In situations where the values did not automatically go up to 5, linear rescaling was needed to adjust the values by rescaling the distance between each state in order to get values of 1-5 again. In order to do this, Equation 7 was implemented:

(5-1)/(n-1) , n = number of the state ……………………….(7)

For example, a hypothetical node has only 4 states. In order to have 5 states, the distances between the states must be changed: (5-1)/(4-1)= 1.33

Results: High = 5

Medium (5-1.33) = 3.67

Low (5-2.66) = 2.33

None = 1

The probability between linked nodes must have equal number of states, and the number of needed states in each linked node is determined by the child node's number of states. So if the child node has five states (very high = 5, high = 4, medium = 3, low = 2, very low = 1) but the parent nodes have an average of 4.335 states, the parent nodes' state must be altered to equal that of the child node. The average of 4.335 has a value more than 4 but less than 5. The probability of the state equaling 4 is 50% plus the extra value of 0.335 x 50, which equals 16.75. So 50% + 16.75% = a probability of 66.75% that the state will equal 4. The probability of the state equaling 5 is represented by the equation 100 – 66.75. Therefore, the probability of the state equaling a value of 5 is 33.25%. Table 11 is an example of these calculations using the rescaling method.

Table 11 Example of the calculations for CPTs using the rescaling method.

			5	4	3	2	1
A	**B**	**Summation (A+B)/n**	**Very High**	**High**	**Medium**	**Low**	**Very Low**
5	5	5.00	100				
5	3.67	4.34	33.25	66.75			
5	2.33	3.67		83.25	16.75		
5	1	3.00			100		
3	5	4.00		100			
3	3.67	3.34		33.25	66.75		
3	2.33	2.67			83.5	16.5	
3	1	2.00				100	
1	5	3.00			100		
1	3.67	2.34			33.25	66.75	
1	2.33	1.67				83.25	16.75
1	1	1.00					100

Note: See the Appendix B for all calculations of every node in this study.

6.2.3 Sensitivity Analysis

Sensitivity analysis is used to test key nodes which may affect longan production. Nodes with high sensitivity may easily affect longan production. This means that even the slightest change in a node of high sensitivity can have significant repercussions. The "Sensitivity to Finding" function in the program Netica is able to determine the influence of each node on the BBN chart as a whole. Table 12 shows the sensitivity analysis results of these tests. The nodes "Crop Management" and "Water Application" were found to have the most significant influence. These two nodes proved to be very important in the production of longan fruit.

Table 12 Results of the Sensitivity Analysis on the Flowchart of the BBN Model

Node	Mutual Information	Variance of Beliefs
Crop Management	0.224	0.039
Water Application	0.139	0.031
Longan Tree Condition	0.120	0.023
Water-use Efficiency	0.032	0.007
Water Situation	0.030	0.007
Flowering Situation	0.010	0.001
Rainfall Suitability*	0.004	0.001
Rainfall level*	0.004	0.001
Plant Fertility	0.002	0.000
Quantity of Fruit	0.001	0.000

**is a node input*

6.3 Model Comparison Using 3 Types of Data

This study created a model on the production of longan fruits based on three types of data. The first type of data originated from the questionnaire filled out by 150 farmers. The second type of data came from interviews with 30 farmers concerning their management of longan orchards. Data concerning about longan yield was also collected from those 30 sampled sites during harvest time. The third type of data had the same 30 sources but was collected from the photos taken of the trees' canopies prior to harvest time through image analysis. The details of these three types of data can be seen in Table 13.

Table 13 Types of Data Used for Creating the Model in this Study.

	Type A	**Type B**	**Type C**
Number of Sources	150	30	30
Information-Gathering Method	Interviews with Farmers	Interviews with Farmers	Interviews with Farmers
Type of Information Source About longan Yield	Questionnaire	First-hand Collection of longan yield during Harvest Time	Image Analysis of Photos Taken of Fruit Area in Canopies

The structure and flowchart from the previous process were used to create the original model which explained the relationships between each node that factored into longan production performance, but the nodes did not have equal numbers of states yet. Therefore, the next step was to equalize them in order to have a proper CPT. The parent nodes "Flowering" and "Activity after Flower Stage" had to correspond with the child node "Yield Prediction," which resulted from the 3 types of data. The nodes were placed into a case file, which was then put through the Netica program, using the Incorp Case File as tool, in order to create a CPT of the relationships among all sets of the data. Figure 60 shows the relationships among these three nodes, and the details of these relationships are displayed in Table 14. The result from CPT are shown in the flowing Table 14-16.

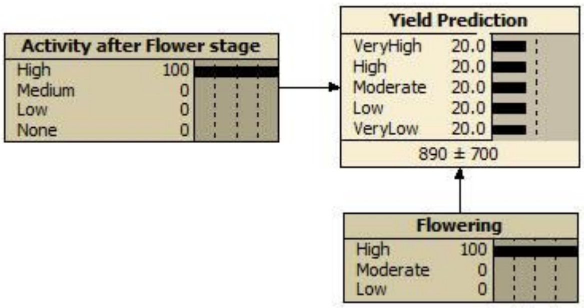


Figure 60 The Relationships between the Parent Nodes and Child Node.

Table 14 Sample of the relationships between "Flowering," "Activity after Flowering Stage," and "Yield Prediction" that may affect longan yield.

Sample	Activity after Flowering Stage	Flowering	Yield Prediction
1	Low	Moderate	Moderate
2	Low	Moderate	Moderate
3	Medium	Moderate	Moderate
4	Low	Moderate	Moderate
5	Low	High	High
6	Low	Moderate	Moderate
7	Low	Moderate	Moderate
8	Low	Moderate	Moderate
9	Low	High	High
10	Medium	Moderate	Moderate

Table 15 CPT Values for the Type A Data.

Flowering	Activity After Flowering Stage	Very High	High	Moderate	Low	Very Low
High	High	0.14	0.43	0.14	0.14	0.14
High	Medium	0.08	0.69	0.08	0.08	0.08
High	Low	0.20	0.60	0.07	0.07	0.07
High	None	0.20	0.20	0.20	0.20	0.20
Moderate	High	0.08	0.08	0.67	0.08	0.08
Moderate	Medium	0.03	0.03	0.87	0.03	0.03
Moderate	Low	0.02	0.02	0.92	0.02	0.02
Moderate	None	0.20	0.20	0.20	0.20	0.20
Low	High	0.17	0.17	0.17	0.33	0.17
Low	Medium	0.05	0.05	0.05	0.70	0.15
Low	Low	0.03	0.03	0.03	0.79	0.12
Low	None	0.17	0.17	0.17	0.33	0.17

Table 16 CPT Values for the Type B Data.

Flowering	Activity After Flowering Stage	Very High	High	Moderate	Low	Very Low
High	High	0.20	0.20	0.20	0.20	0.20
High	Medium	0.14	0.43	0.14	0.14	0.14
High	Low	0.13	0.50	0.13	0.13	0.13
High	None	0.20	0.20	0.20	0.20	0.20
Moderate	High	0.20	0.20	0.20	0.20	0.20
Moderate	Medium	0.08	0.08	0.69	0.08	0.08
Moderate	Low	0.05	0.05	0.79	0.05	0.05
Moderate	None	0.20	0.20	0.20	0.20	0.20
Low	High	0.20	0.20	0.20	0.20	0.20
Low	Medium	0.17	0.17	0.33	0.17	0.17
Low	Low	0.17	0.17	0.17	0.33	0.17
Low	None	0.20	0.20	0.20	0.20	0.20

Table 17 CPT Values for the Type C Data.

Flowering	Activity After Flowering Stage	Very High	High	Moderate	Low	Very Low
High	High	0.20	0.20	0.20	0.20	0.20
High	Medium	0.29	0.14	0.14	0.29	0.14
High	Low	0.25	0.25	0.25	0.13	0.13
High	None	0.20	0.20	0.20	0.20	0.20
Moderate	High	0.20	0.20	0.20	0.20	0.20
Moderate	Medium	0.23	0.08	0.38	0.23	0.08
Moderate	Low	0.05	0.16	0.32	0.26	0.21
Moderate	None	0.20	0.20	0.20	0.20	0.20
Low	High	0.20	0.20	0.20	0.20	0.20
Low	Medium	0.17	0.17	0.33	0.17	0.17
Low	Low	0.17	0.17	0.17	0.33	0.17
Low	None	0.20	0.20	0.20	0.20	0.20

6.4 Longan Yield Predictions from BBN

The following are BBN models created for each data type in order to predict longan production.

6.4.1 Type A Data Model

The model in Figure 61 predicted the highest probability 48.8% for production at a medium output range of 500-1,000 kg/rai., The second highest probability (24.8%) was predicted for a high output at 1,000-1,500 kg/rai. There was a 12.4% probability predicting the output at 200-500 kg/rai (a low production yield), an 8.07% probability for 1,500-2,500 kg/rai, and a 5.88% probability for 0-200 kg/rai. The predicted average yield level was 887 kg/rai.

6.4.2 Type B Data Model

The model in Figure 62 predicted the highest probability 46.5 for production at a medium output range of 500-1,000 kg/rai., The second highest probability (22.3%) was predicted for a high output at 1,000-1,500 kg/rai. There was an 11.2% probability predicting the output at 200-500 kg/rai (a low production yield), a 9.97% probability for 1,500-2,500 kg/rai, and a 9.97% probability for 0-200 kg/rai. The predicted average yield level was 877 kg/rai.

6.4.3 Type C Data Model

The model in Figure 63 predicted the highest probability 28.1% for production at a medium output range of 500-1,000 kg/rai., The second highest probability (23.0%) was predicted for 200-500 kg/rai. There was a 17.8% probability predicting the output at 1,500-2,500 kg/rai (the highest production rate), a 16.2% probability for 1,000-1,500 kg/rai, and a 15.0% probability at 0-200 kg/rai (the lowest production rate). The predicted average yield level was 863 kg/rai.

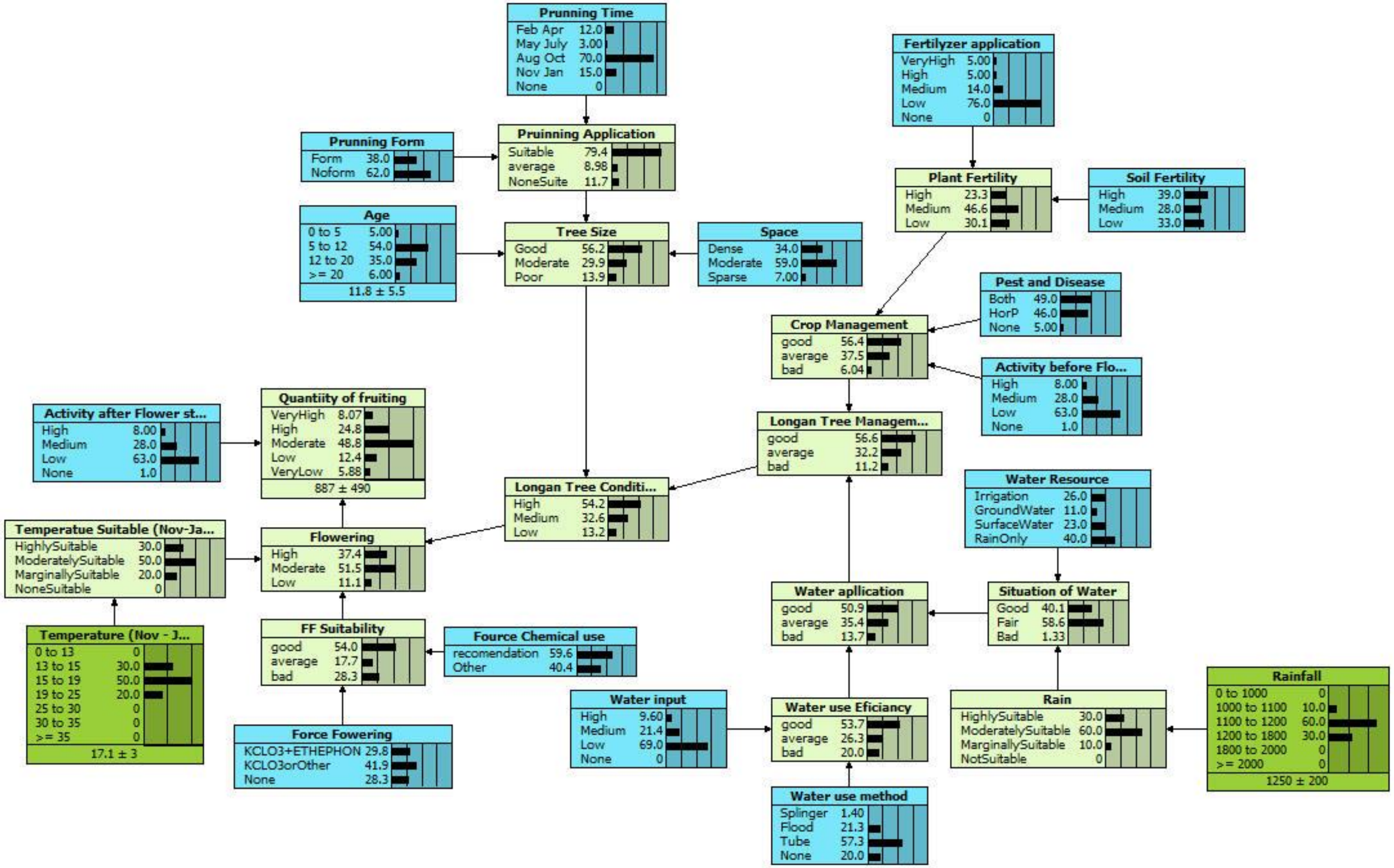


Figure 61 Type A Data Model.

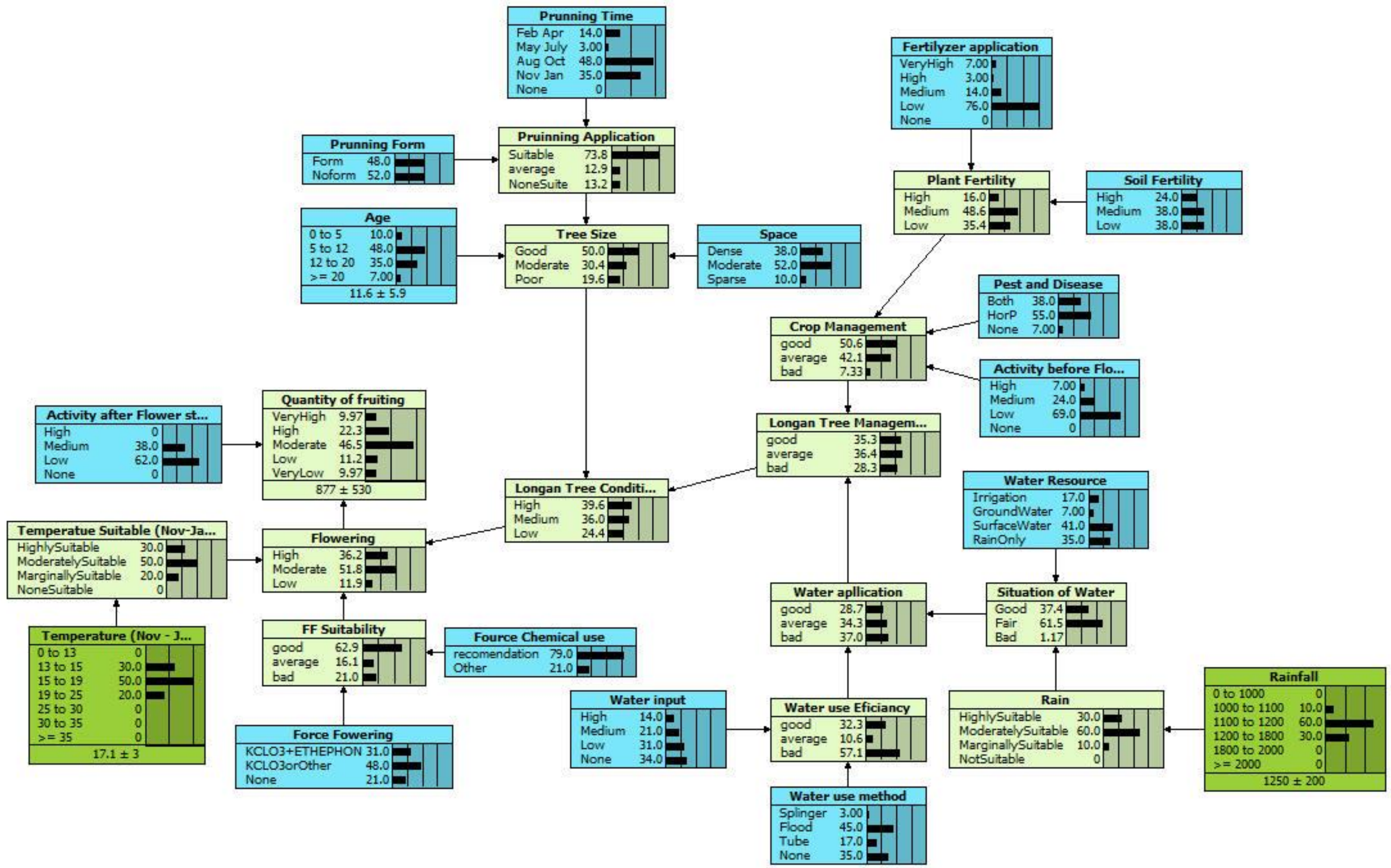


Figure 62 Type B Data Model.

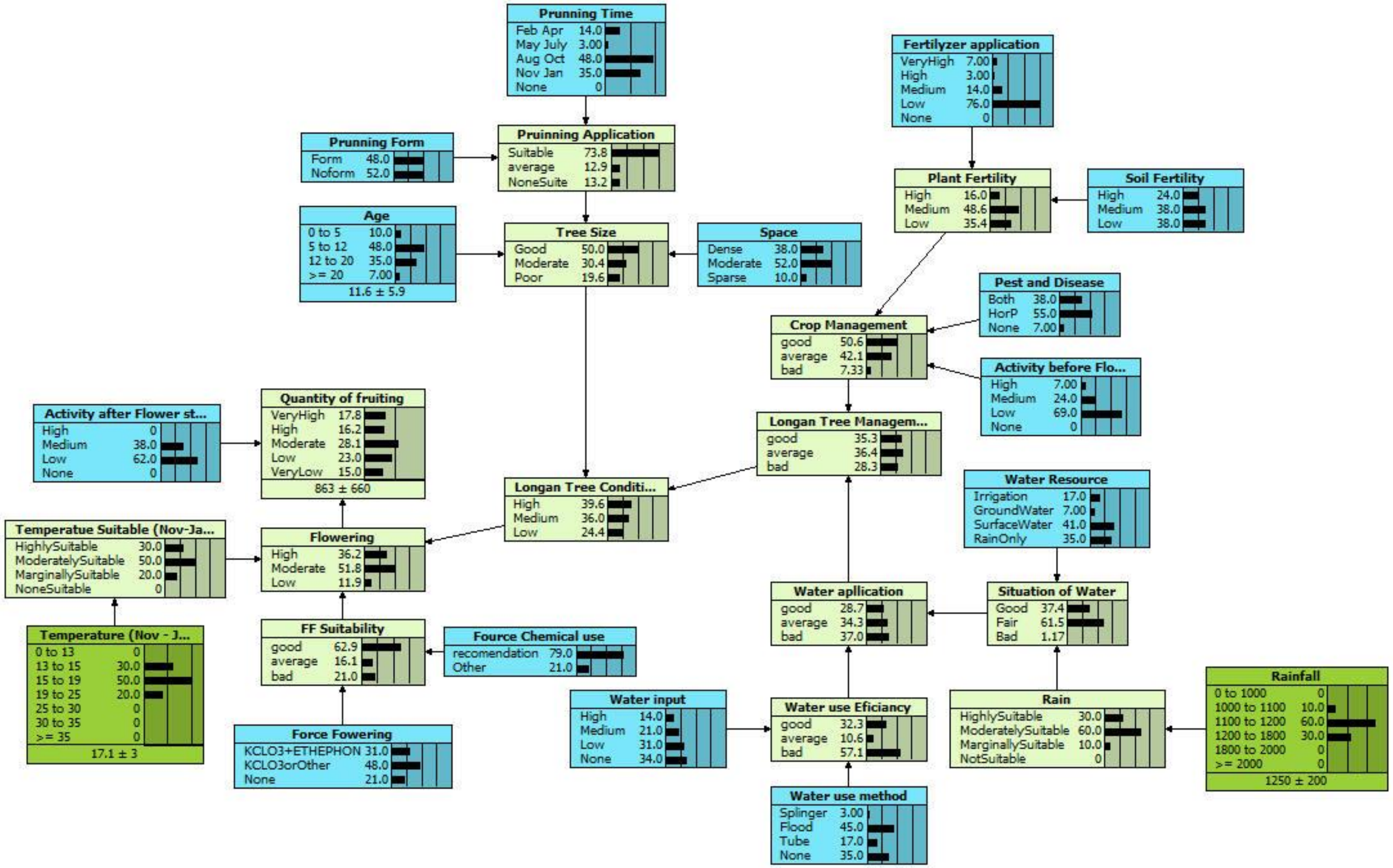


Figure 63 Type C Data Model.

From these three models, the three types of data were analyzed and compared (Table 18). The table shows that the predicted average yield from the Type A model was 867 kg/rai. which is different from the actual average 744 kg/rai. based on the data given by the farmers. Thus, there is a discrepancy of 123 kg/rai or a difference by 16.5%. The Type B model has resulted in a difference of 15 kg/rai or by 1.7% between the model's prediction and the actual result (871 - 884). The Type C model predicted an average yield of 867 kg/rai. While the actual result was 780 kg/rai, so there is a difference of 87 kg/rai or by 11.2%.

Table 18 Comparison of the Predictions of the Three Models and the Actual yields.

Production Level	**Type A**		**Type B**		**Type C**	
	Observe	**Simulate**	**Observe**	**Simulate**	**Observe**	**Simulate**
Average (kg/rai)	744	867	871	884	780	867
Highest (kg/rai)	2,500	1,100	1,350	952	2,481	960
Lowest (kg/rai)	100	491	417	787	55	728

6.5 Accuracy Assessment of the BBN Models

The models were assessed by their RMSE and RMSEn values. The predictions were compared to the actual yields. The results are displayed in Table 19.

Table 19 Results of the Assessment of the Accuracy for Models A, B, and C.

	Observation		**BBN**			
	Mean	SD	Mean	SD	RMSE	RMSEn
Type A	744	330	867	109	44.7	6.0
Type B	871	177	884	51	20.2	2.3
Type C	780	593	867	84	73.3	9.4

The data concerning the Type A model had an actual average of 744 kg/rai with a standard deviation of ±330, but the model's prediction was averaged at 867 kg/rai with a standard deviation of ±109. The model's RMSE value was 44.7 and its RMSEn value was 6. In conclusion Type A model has a high rate of errors.

The data concerning the Type B model had an actual average of 871 kg/rai with a standard deviation of ±177, but the model's prediction was averaged at 884 kg/rai with a standard deviation of ±51. The model's RMSE value was 20.25 and its RMSEn value was 2.3. In conclusion, Type B model had a low enough rate of error and thus can to be acceptable

The data concerning the Type C model had an actual average of 780 kg/rai with a standard deviation of ±593, but the model's prediction was averaged at 867 kg/rai with a standard deviation of ±84. The model's RMSE value was 73.3 and its RMSEn value was 9.4. In conclusion, Type C model also has a high rate of error.

The above results of the accuracy assessment showed that the Type B model had the lowest error and therefore was the most acceptable model for the prediction of longan output.

Management scenario testing was done on the Type B model with a special focus on the various management practices in longan production. The goal was to compare the best management practice with the worst one. This was done by changing the input probability values of every node in the model to their highest (best) settings to generate the result representing the best management practice. All nodes' probability values each were then changed to their lowest (worst) settings in order to capture the worst management practice. The model predicted that the best management practice would produce an average longan yield of 1,230 kg/rai and the worst management practice would result in 488 kg/rai (Figure 64 and 65).

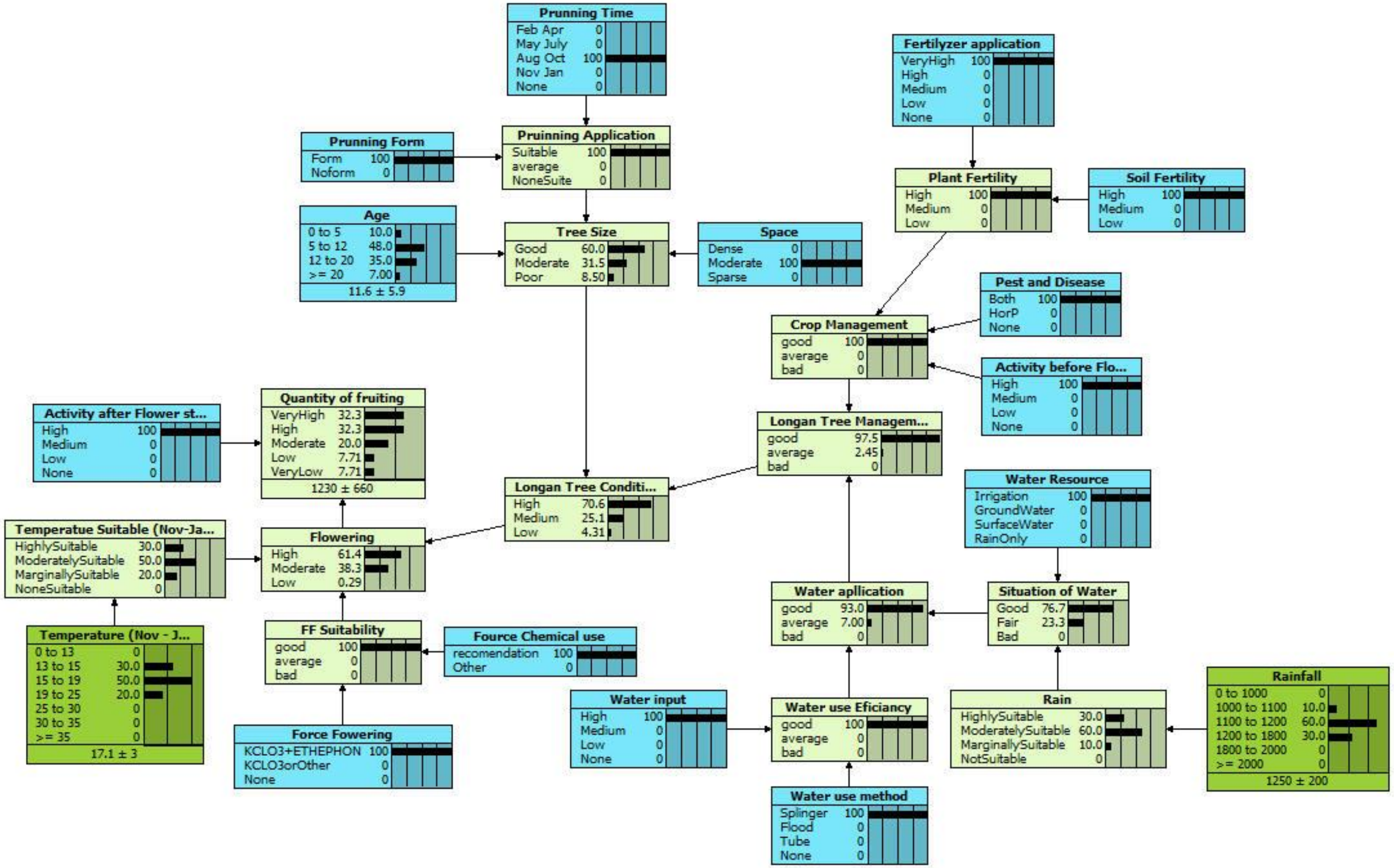


Figure 64 Model for best practices.

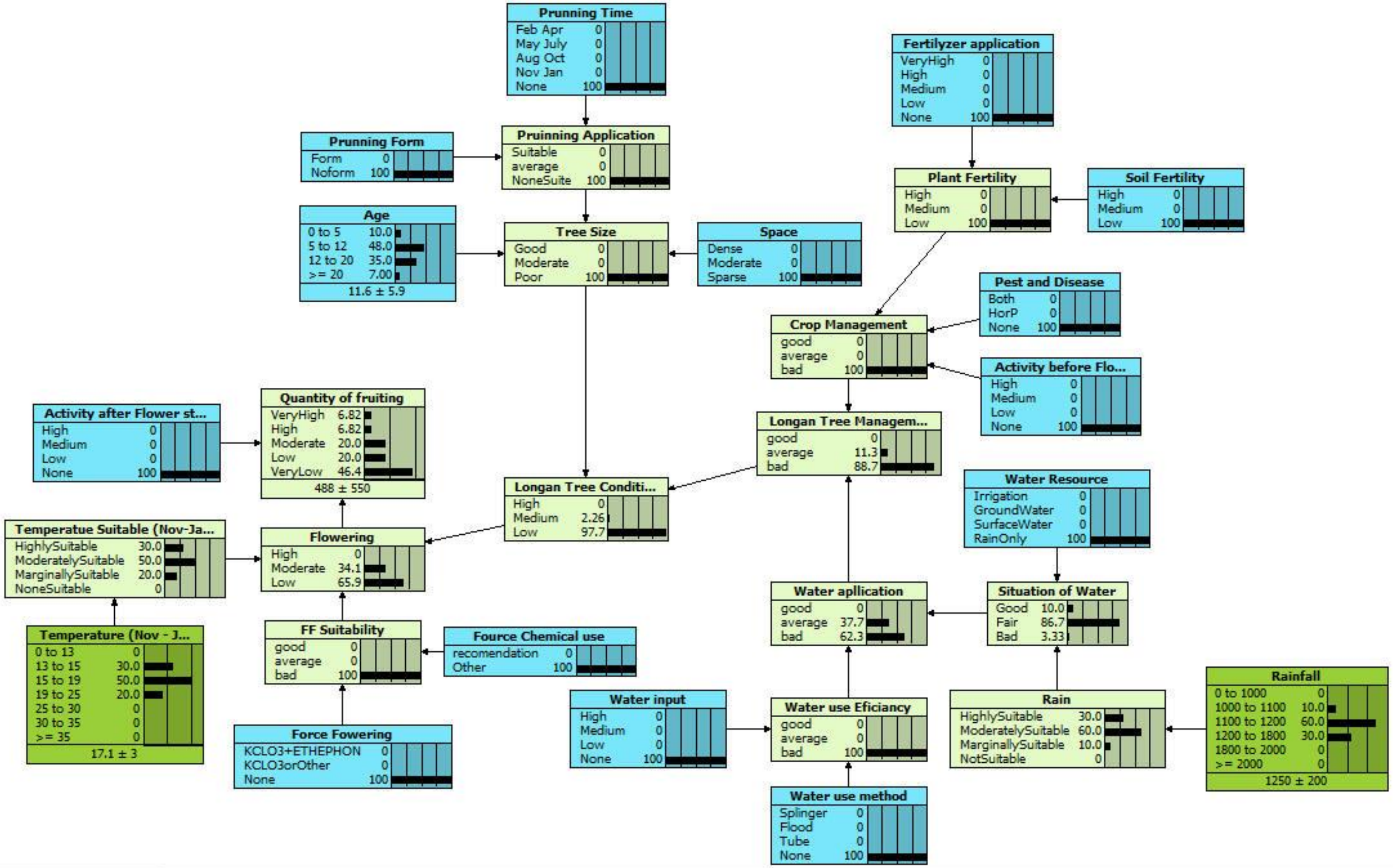


Figure 65 Model for bad practices.

Next in the testing process, with all nodes at their highest settings, individual node was set to its lowest setting to see what would change in the predictions; for example, putting the node for pruning application at its lowest setting, or any other one about using fertilizer, or watering, or using the chemical $KClO_3$. The results for each of these tests are displayed in Table 20.

Table 20 Difference in the average yield after manipulating management practices

Management Practices	Average Production (kg/rai)	Difference From Best Production (kg/rai)
Best Management Practices	1,230	0
Best Practices, no pruning application	1,120	110
Best Practices, no fertilizers	1,210	20
Best Practices, no watering	1,170	60
Best Practices, no use of $KClO_3$	956	274
Worst Management Practices	488	742

Table 20 shows that yield from the best management practice was predicted at 1,230 kg/rai. Changing any of the factors in the management practice causes a difference in the predicted result. The change that affected the result the most was excluding the use of $KClO_3$ which entitled the predicted yield to be 956 kg/rai, which is a difference of 274 kg/rai from the best result. Excluding the trimming of branches caused the model to predict an average yield of 1,120 kg/rai, which is a difference of 110 kg/rai from the best circumstance.

Excluding watering caused the model to predict an average yield of 1,170 kg/rai which is a difference of 60 kg/rai from the best result. Excluding the use of fertilizers proved to cause the least change in the yield level which was predicted to be 1,210 kg/rai on average which is only 20 kg/rai less than the best result. The worst management practice was referred to the case having no applications of any yield enhancing factors.

Using the BBN Model in this study has shown the impact different management practices would have on longan yield and output in the research area. Choosing whether or not to use chemicals which encourage flowering (chemicals with $KClO_3$) has the biggest impact on yield level. The choices to trim the branches and to water the trees have the next highest impact. According to the model, the choice with the least amount of impact is whether to use fertilizers or not. These data will prove to be very beneficial for helping farmers make management decisions in the future.

6.6 The Maps of Longan Yield Prediction.

This study created LMUs with three types of spatial data: tree age, watering methods, and landscape characteristics. There were 27 categories of these data (LMU); but based on the comments from farmers, it was determined that land characteristics did not significantly impact longan fruit production rates, so only tree age and watering methods remained as factors, resulting in a total of 16 LMU. This information was then added to the BBN model to improve its prediction for each LMU's production level, as shown in Table 21.

Table 21 LMU and the Corresponding Predicted Longan Yield and Output.

LMU	**Count**	**Area (rai)**	**Yield (kg/rai)**	**Output (kg)**
0 - 5 years_irrigation system	10	67	860	57,360
0 - 5 years_groundwater	25	152	860	130,421
0 - 5 years_ Surface Water and Water Bodies	316	3,525	860	3,031,114
0 - 5 years_rainfall	628	2,410	855	2,060,491
6 - 12 years_irrigation system	112	431	878	378,392
6 - 12 years_groundwater	128	1,527	878	1,340,636
6 - 12 years_ Surface Water and Water Bodies	705	9,393	877	8,238,029
6 - 12 years_rainfall	1,992	12,253	877	10,745,653
13 - 20 years_irrigation system	38	124	878	109,196
13 - 20 years_groundwater	58	463	878	406,784
13 - 20 years_mountain & surface water	424	3,358	877	2,944,832
13 - 20 years_rainfall	700	5,932	877	5,202,758
21 - 30 years_irrigation system	1	1	876	561
21 - 30 years_groundwater	12	104	876	91,007
21 - 30 years_mountain & surface water	27	213	876	186,616
21 - 30 years_rainfall	73	448	876	392,368
Total	5249	40401	872	35,316,227

The results from each LMU were used to create a map which predicts the production level in each LMU throughout Phrao District. This process was done by multiplying the production area by the total number of rai for each farm (Figure 66).

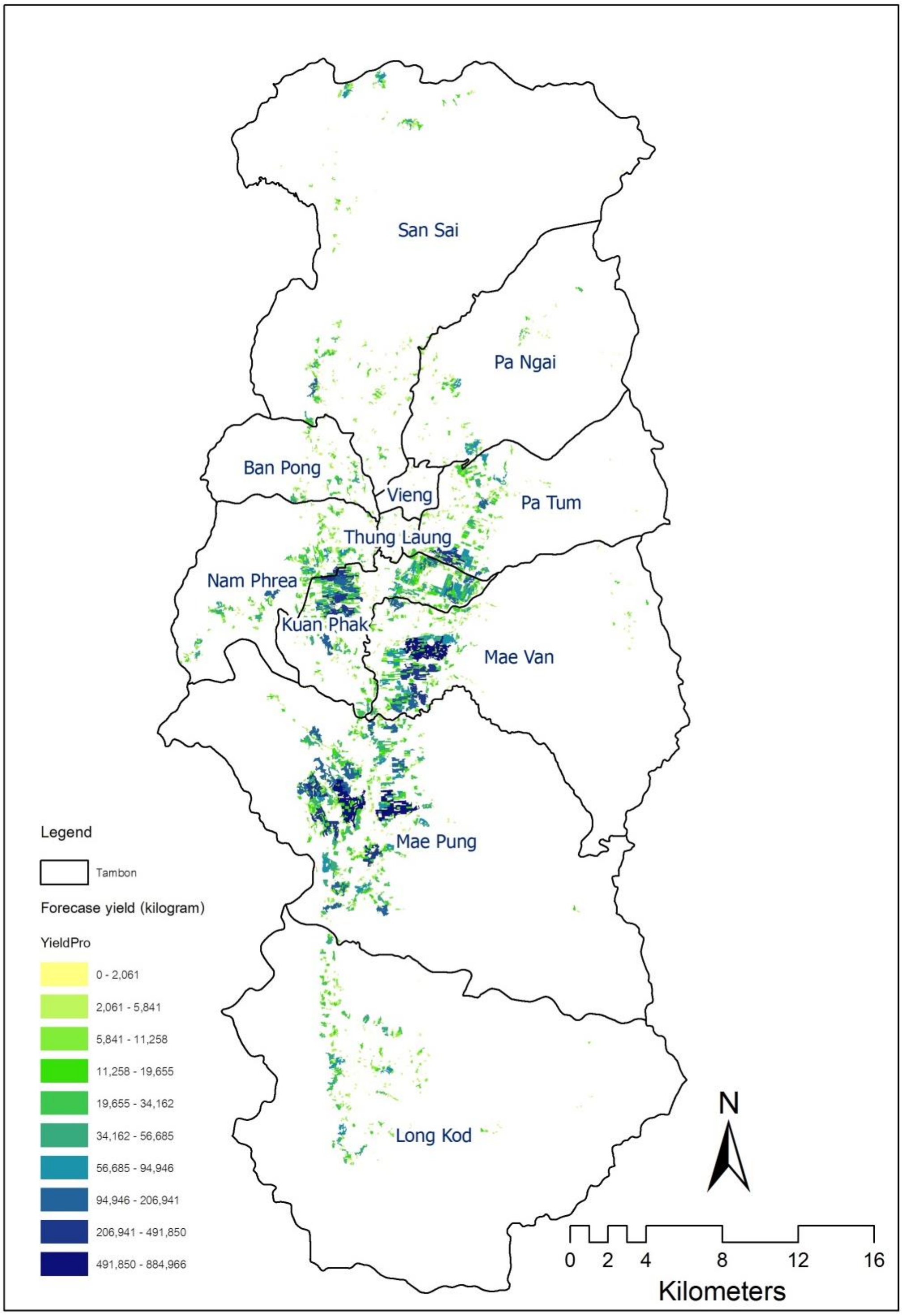


Figure 66 Map predicting the area distribution of longan production in Phrao District.

The map predicts that the most prolific longan production (more than 100,000 kg/farm) will take place in the central region of the District, especially in Kuan Phak, Mae Van, and Mae Pung sub-district. All other areas in Phrao district are predicted to produce at lower performance rates. However, there are areas of high productivity predicted elsewhere, like Pa Tum sub-district. Most of the land in Phrao district is predicted to produce at a moderate output levels of 20,000 – 100,000 kg/farm. Altogether, the District is predicted to produce 35,316,227 kg or 35,316 tons of longan fruits.

The LMU with the highest total output of longan fruits belong to the group containing trees aged 6 to 20 years and which have orchards mostly watered through rainfall alone. This group had the highest total output because it has most sample farms in its group, and the difference between each farm's longan yield throughout Phrao district was not very great. As for the other LMU, their output levels were not significantly different from one another; the key factor was the size of the land devoted to longan orchards.

Phrao district has a total of 11 sub-district. The total area devoted to longan production is 40,400 rai. The sub-district with the largest extent of land used for longan production is Mae Pung with a total of 12,161 rai. Vieng sub-district has the least extent of land used for longan production at 43 rai. When compared with the actual extent and location of land registered under longan production with the Department of Agriculture in Phrao district, the map in Figure 64 is very accurate. The official registration report claims a total of 34,945 rai used for longan production, which is only 5,000 rai less than what the map shows. The same ratio of difference can also be seen in individual sub-district: Mae Pung, Kuan Phak, Long Kod, Pa Ngai, etc. The ratio of difference could be due to several reasons, such as the misidentification of other trees as longan orchards or farmers failing to report the actual size of their land used for longan orchards. When the results from the map were used in combination with BBN model, it was predicted that the total production will be 35,316,227 kg. As for Mae Pung sub-district, which has the highest output total, it was predicted to produce 10.6 million kg. Mae Van and Kuan Phak sub-district had the second highest output totals predicted. Vieng sub-district had the lowest output total at 62,009 kg, and Thung Luang sub-district was predicted to produce 142,590 kg. All of these predictions are based on the sizes of the lands used for longan production.These predictions were compared with the conventional predictions made by the staff of the Department of Agriculture. The staff's conventional method is to randomly sample farms from each sub-district and ask the owners of the land how much they expect to harvest for that year. The staff determined that the output levels depend on the behavior of the longan trees through their "on year/off year" cycle. When longan trees produce a lot of fruits, they are having an "on year." If they don't produce well, it is their "off year." For example, 2010 was an off year due to droughts, but 2011 was an on year since production was at a high level again. The DOA staff's prediction for 2010 was a total production of 27,956,000 kg (with an average of 691 kg/rai). The staff predicted a total production of 34,945,000 kg (with an average of 864 kg/rai) for the year 2011. These predictions are different from what generated by the model of this study because this study incorporated the use of LMUs. There are many other factors which may have also influenced the difference between the two predictions. There are differences between the predictions for each sub-district's total longan output as well. Table 22 shows the comparison of the BBN model's predictions with the Department of Agriculture's predictions for each sub-district.

Table 22 The Longan Planted Areas of Each Sub-district with the Predictions made by the BBN Model and the Department of Agriculture

Sub-district	**Land Area (rai)**[1]	**BBN Model Prediction (kg)**[2]	**Land Area Registered (rai)**[3]	**Prediction for 2009/2010 (kg)**[4]	**Prediction for 2010/2011 (kg)**[5]
ThungLuang	151	142,590	504	403,200	504,000
Nam Phrae	3,203	3,216,798	2,012	1,609,600	2,012,000
Ban Pong	891	854,363	1,178	942,400	1,178,000
Pa Tum	3,573	3,474,140	2,034	1,627,200	2,034,000
Pa Ngai	1,055	1,050,487	1,379	1,103,200	1,379,000
San Sai	2,318	2,106,088	1,560	1,248,000	1,560,000
Kuan Phak	7,969	7,582,402	6,087	4,869,600	6,087,000
Vieng	43	62,009	586	468,800	586,000
Mae Pung	12,161	10,664,012	11,259	9,007,200	11,259,000
Mae Van	6,096	5,606,359	5,540	4,432,000	5,540,000
Long Kod	2,939	2,579,330	2,806	2,244,800	2,806,000
Total	40,400	35,316,227	34,945	27,956,000	34,945,000

Resources: [1] from the spatial database, [2] BBN Model,

[3,4,5] from the Department of Agriculture in Phrao District

[3] this is the land registered at the Department of Agriculture

[4] the Department of Agriculture's predictions for 2009/2010

[5] the Department of Agriculture's predictions for 2010/2011