Chapter 2

Literature Review

Rice is indispensable in the Bhutanese culture, tradition and religion. It is a way of life and the livelihood itself. Traditionally, Bhutan was self-sufficient with rice, and there use to be enough for export and exchange with neighboring countries. Today the situation has changed and Bhutan imports annually 38,800 t/year of rice to meet its consumption requirement. Self sufficiency level of rice varies greatly according to different sources which ranges from 39% to 56%. Apparently, this has generated serious concerns at the national and household level. As a result, government has always attached high priority for the development of rice through out its planned development. Accordingly, Ministry of Agriculture has set an objective to achieve and maintain the food self-sufficiency level to 70% (DRDS, 2001).

2.1 Development program and strategy

Rice research in Bhutan is coordinated by the Renewal Natural Resources Research Centre (RNR-RC), Bajo, Wangdue. Within its short history of rice research, the centre has produced 15 improved rice varieties for different locations (Table 2.1). Out of the fifteen varieties released so far, ten varieties are suitable for mid altitude, i.e., 600m to 1800m.

Table 2.1: Rice varieties released by RNR-RC, Bajo.

Variety name(local/given)	Year of release	Recommended agro-ecology zone	
		Altitude	Crop Season
		-----m-----	
Yusi Ray Kaap	2002	>1,800	Main crop
Yusi Ray Maap	2002	>1,800	Main crop
Khangma Maap	1999	Above 1,500	Main Single
No 11		Above 1,500	Main Single
IR-64	1988	600-1,500	Main Single
Milyang 54	1989	600-1,500	Main Single
IR 20913	1989	600-1,500	Second Double
		Up to 600	Spring Double
		600-1,500	First Double
BW 293	1990	Up to 600	Main Single
Barket	1992	600-1,500	First Double
Bajo Maap 1	1999	600-1,500	Main single
Bajo Maap 2	1999	600-1,500	Main single
Bajo Kaap1	1999	600-1,500	Main single
Bajo Kaap 2	1999	600-1,500	Main single
Khumal 2	2002	600-1,500	Main crop
BR 153	1989	Up to 600	Main Single

(Source: Ghimiray, 2003a).

National objectives for rice development are derived from the concerns of farming communities rather than pushing them to achieve the objectives set by the Ministry. Area specific distribution of rice variety suggests that scope and emphasis of rice production is not same through out the country (DRDS, 2003).

Potential production areas in all the agro-ecological zones across the country are identified with potential production level (Table 2.2). Use of improved varieties, proper nutrient use and cultural practices are aimed at improving present production level. Priorities for irrigation infrastructures development are being identified and importance of water management at farm level considered important.

Table 2.2: District wise rice production potential and area.

AEZ	District	Rice area	Current rice yield	Potential target yield	Estimated present production
		--ha--	----------t/ha----------		-----t-----
WT	Thimphu*	1,595	4.5	5.5	7,178
	Paro	2,323	3.5	5.0	8,131
DST	Wangdue*	3,905	3.5	5.0	13,668
	Punakha*	3,209	3.5	5.5	11,232
	Trongsa	1,942	2.1	3.5	4,078
	Trashigang	1,639	2.4	3.5	3,934
	Lhuentse	933	2.3	3.5	2,146
HST	Tsirang	2,266	1.5	3.0	3,399
	Dagana	2,090	2.3	3.3	4,807
	T/yangtse	1,996	2.3	3.3	4,591
	Chukha	1,017	1.7	3.0	1,729
	Zhemgang	1,101	1.9	2.5	2,092
WST	Sarpang	4,474	2.0	3.0	8,948
	Samtse	6,208	1.9	3.0	11,795
	S/jongkhar	2,162	2.5	3.5	5,405
	Average	-	2.7	3.9	-

(Source: DRDS, 2001).

Note:* Study Sites

Efforts are put in to developed modern varieties for warm temperate zone, which has high production potential. Many trials and variety improvement programs are being conducted in high altitudes. Inputs supply are improved and made available at reasonable prices and quality. To address the labor problem farm mechanization is encouraged and farm machineries are provided at highly subsidized rate. Rural credit is provided and farm roads construction taken up as priority program to connect production and market.

2.2 Production constraints

Farmers still use traditional production practices and grow traditional varieties with low inputs. However, with the development intervention, modern varieties are introduced but the acceptance of those varieties among farmers is slow due to high input requirement such as fertilizer. Further, inadequate arrangement exist for managing and sharing risk associated with introduction of new techniques and changes in traditional diversified farming system (DRDS, 2003).

Other major problem is labor shortage, on an average 205 labor days is required to grow one hectare of rice. Import of cheaper rice from India is yet another discouragement for growing improved high yielding varieties. Loss of paddy land to other land use form due to modernization and natural calamities is also a contributing factor to low production. Further, with the changing economy farmers are switching from rice to other profitable enterprises. Inadequate irrigation and poor market accessibility and infrastructure are also considered as constraints for improving rice yield.

2.3 Production opportunities

Based on altitude, temperature and rainfall, five major agro-ecological zones are identified as cool temperate, warm temperate, dry subtropical, humid subtropical and wet subtropical (Table 2.3). Cool temperate is not climatically suitable for rice production so rice is grown in remaining four zones (Ghimiray, 2003a). The maximum potential for rice production is in the warm temperate zone, which fall within the altitude of 1,800m to 2,600m, because of cooler temperature at grain filling and ripening stage, relative freedom from insect pest and diseases, high solar radiation etc. However, there are limited modern varieties suitable for this zone. Next potential zone is dry sub tropical zone with relatively low pest and disease problem and high solar radiation. Also, many modern varieties bred are also suitable for this zone. Along with modern varieties improved management practices are also promoted as package. Apart from climatic potential, this zone is favored by relatively fertile soil.

Table 2.3: Agro ecological zones (AEZ) of Bhutan.

A E Z	Altitude	Temperature			Rainfall	Districts
		Max	Min	Mean		
	-----m-----		------------^{0}C-----------		---mm---	
CT	2,600-3,600	22	1	10	650-850	Bumthang, Gasa
WT	1,800-2,600	26	1	13	650-850	Thimphu, Paro, Lhuentse, Trashigang
DST	1,200-1,800	29	3	17	850-1,200	Wangdue, Punakha, Trongsa, Trashigang, Mongar, Lhuentse
HST	600-1,200	33	5	20	1,200-1,500	Tsirang, Dagana, Chukha, Zhemgang, Pemagatshel, Trashiyangtse
WST	<600	35	12	24	2,500-5,500	Sarpang, Samtse, Samdrupjongkhar

(Source: Ghimiray, 2003a).

Further, government's policy of maintaining 70% food self-sufficiency and giving rice development high priority is a positive environment for increasing production. More importantly, food habit of Bhutanese people in itself is a driving force for increasing rice production.

2.4 Farming system in Bhutan

Farming activities in Bhutan includes all land based activities such as cropping, horticulture, animal husbandry and forestry. Due to high variation in climate and altitudes within a small area there exist different types of farming systems. Five principle farming systems are practiced in the Hindu Kush- Himalayan region (HKH) which includes Bhutan (Ya and Tulachand, 2003). These systems are pastoral, agro-pastoral, food grain crops dominated, horticultural crops led and shifting (slash and burn) systems. Upadhyay (1995) has classified farming system in Bhutan into three broad types, namely; pastoral-transhumance system, subsistence-level crop and animal husbandry, and pre commercial farming.

Pastoral farming systems or pastoral transhumant system comprises 100% livestock, which is practiced by semi-nomad people moving from one place to another. This type of system is found in highland areas with an altitude of 2,400 to 4,500m, often known as "yak zone" of Gasa, Merak and Sakten including some parts of Bumthang, Paro and Haa districts. During winters, when temperature drops below and feed availability becomes scarce animal herds are migrated to warmer places in the lower valleys. At lower altitudes, they trade livestock products and buy necessary consumer items, including low altitude food crops like rice.

Agro pastoral system exists in some higher altitude districts, where livestock production system is supplemented by subsistence food grain production (Ya and Tulachand, 2003). During summer they cultivate their land with barley, millet and buckwheat.

Most common farming system in Bhutan is integrated farming systems, which commonly consists of cereal crops, horticultural crops and livestock. It is still subsistence in nature and practiced by about 90% of Bhutanese farmers (Upadhayay, 1995). Production from this system is consumed by farmers themselves and very little is traded in the market. Commonly traded commodities are rice, fruits, vegetables and diary products. Small trading that take place is seasonal and cash income is used for purchasing household necessities, children's education, religious ceremonies and buying fertilizer and other inputs for farming. However, composition of crop and livestock in the farming systems varies dramatically over the country, and even from village to village (Wissink, 2004). This system is also sometime known as high land mixed farming system (Weatherhogg, *et al*., 2001).

With the government intervention and opening up of market access, many farmers though in small amount have started commercial farming in recent years (Upadhayay, 1995). Commercial farming of potato, apple, orange, cardamom chilly and vegetables has become successful due to introduction of improved varieties and management practices along with infrastructure development and enabling policy support put in place by the government. Another important farming system that exists in Bhutan, predominantly in eastern part is shifting cultivation (slash-and-burn) (Jodha, 1990). Shifting agriculture is now at a cross-road as government has put restriction on it with an objective of protecting forest coverage.

2.5 Rice farming system

Within the subsistence integrated farming system, wetland rice based farming system is considered most important as it is intensively cultivated for paddy by farmers and sharecroppers. Wetland production system comprises of 21% of the actually operated arable land and extends from elevation of 300m to 2,600m. Total rice area in the country varies according to different sources (Table 2.4).

Table 2.4: Rice area, production and yield according to different data source.

Data Source	Area	Production	Yield
	-----ha-----	-----t-----	-----t/ha-----
CSO database, 2001	26,010	39,790	1.53
RNR statistic, 2002	19,396	44,298	2.28
Cadastral survey, 1999	26,512	59,685	2.25
MoA, 1997	23,679	63,065	2.66
GIS-LUPP, 1995	39,240	88,338	2.25
FAO database, 2001	30,000	50,000	1.67
Average	27,473	57,529	2.11

(Source: Shrestha, 2004).

Increasing food production and achieving self sufficiency is a national priority. Ministry of Agriculture has set an objective of achieving 70% food self-sufficiency level by the end of 2007. Food self sufficiency in Bhutanese context is largely interpreted to mean self–sufficiency in rice (Shrestha, 2004). Every Bhutanese prefer to eat rice.

Single rice cropping system was the most dominant cropping system traditionally but rice-wheat and rice-mustard and rice – vegetables cropping system is increasingly taking place with development intervention (Chettri *et al*., 2003). Rice–rice and rice-potato cropping patterns are also seen in some part of the country especially in warm valleys and temperate region respectively. Different rice cropping systems are actually governed by climatic condition and trend of commercialization.

Single rice cropping system consists of nearly 90% of overall rice production system. It is mainly grown in rainy season starting from June-July and harvested in October- November. Rice is grown in four agro-ecological zones in Bhutan – Warm temperate, dry sub-tropical, Humid sub-tropical and wet sub-tropical (Ghimiray, 2003a). Dry sub-tropical zone which falls under mid altitude (1,200-1,500m) with low rainfall 850-1,200mm annually, consist of major rice growing area with a higher yield potential because of high solar radiation and long ripening phase (Ghimiray, 2003b). With intensification of rice based cropping system, issue of nutrient management has become important. Farmers are forced to supplement the nutrient requirement by inorganic fertilizers (Chettri *et al.*, 2003). In many parts of the country, growing single rice crop is still common and farmers still prefer to grow traditional varieties as these requires less inputs and also the grain quality of high yielding varieties are unacceptable to farmers and straw yield is less (Thinlay *et al.*, 1999). Growing traditional varieties is also attached with culture and tradition. More than 80% of the rice area is under traditional rice varieties, reflecting the high adaptability and suitability of these varieties in traditional farming systems (Ghimiray, 2003a). While, Thinlay *et al.* (1999) reported that 90% of the total rice area is under traditional varieties and farmers grow more than one cultivar.

2.6 System simulation and crop models

System approach and simulation technique have been used by engineers over 30 years (Jintrawet, 1995). The use of simulation model is becoming popular because it provides wide and highly functional approach for simulating the system which consequently can be used in analyzing such systems (Jongkaewwattana, 1995). Other important reason for increasing popularity of system modeling is availability of simulation software and cheap powerful computers. The approach is being characterized in three terms (i) system, (ii) model, and (iii) simulation.

A system exists and operates in time and space. Dent and Blackie (1979) defined system as a complex set of related components within an autonomous framework. Gordon (1969) stated that system in an aggregation or assemblage of objects joined in some regular interaction and interdependence. Model is simple representation of a system at some particular point in time or space intended to promote understanding of the real system. It is used to mimic real system. Many simulation use physical model but there is another type of models called symbolic, it is abstract in form and difficult to understand than physical model (Jongkaewwattana, 1995). Symbolic models are grouped into qualitative and quantitative; qualitative model is system conceptual model while quantitative on the other hand present the system behavior quantitatively. Quantitative model is further divided in to empirical and mechanistic model. Mechanistic model uses mathematical function to represent and explain the relationship (Jongkaewwattana, 1995). Crop simulation models that are used in agriculture production system are mechanistic model.

With the rapid development of computer technology, many crop simulation models have been developed for agriculture systems. Agricultural production systems are complex as it varies from one location to another and understanding this complexity requires systematic research and lots of resources. But it is evident from the recent development that resources for agricultural research are becoming scarce. Field experiment can only be used to investigate very limited numbers of variables under a few site specific conditions (Timsina *et al.*, 2003). On the other hand, crops models are useful tools for integrating knowledge of the bio-physical processes governing the plant soil atmosphere system. There are many crop simulation models; some are generic while others are specific for certain purposes. Most of these models simulate crops growth and soil processes using daily time steps. All models are developed with some assumption and hypothesis and all have strength, weaknesses and limitations. Well know crops modeling groups are IBSNAT/IFDC (International Benchmark Site Network for Agro technology Transfer/International Fertilizer Development Centre) in USA, WAU/AB-DLO (Wageningen Agriculture University/ Centre for Agro biological Research) in Netherlands, and APSRU (Agriculture Production Research Unit) in Australia. As per Matthews and Stephen (2002) application of crop model are broadly grouped into three categories: Research, decision support and education and training.

Two main objectives of agriculture enterprises are to minimize the cost and maximize the output and it is always difficult to balance. Minimizing cost and maximizing production largely depends on the environment (soil, rainfall and temperature) where the crops are grown (Ogoshi *et al*., 1998) but the production environment differs from location to location and also within the farm. Field experiments can produce new data that can improve our understanding of plant and soil processes, while crop simulation models which can imitate the behavior of real plant can integrate new understanding and biophysical environment thus reducing the burden of conducting field experiments in many locations and at the same time cutting research cost and time. Lansigan (1998) mentioned that crop models combined with databases of weather and soil for different locations with varying agro environments can facilitate the use of interdisciplinary knowledge for better understanding of yield gaps and associated temporal and spatial variability.

Tsuji *et al*. (2002) also mentioned that transfer of new technologies are normally done by trial and error field trials, though this method provided scientist with wealth of knowledge, it is time consuming and expensive. Therefore to reduce the cost and time, models can be used to screen the initial trails and field test only the promising ones.

Mentioning about the assessment of technology using simulation model, Jintrawet (1995) stated that it provides choices for farmers, not of the technology itself but of their out comes. He also stressed that model can simulate weather pattern for long term there by allowing farmers to plan adequate strategies to avoid risk attached with particular time of the year. However, he emphasized that simulation model are not intended to replace field experiment but it helps to screen alternative strategies so that only the most promising options are field-tested.

2.7 Decision support system for agrotechnology transfer (DSSAT)

Rapidly changing agriculture technologies and the urgency of the perceived need of least developed countries (LDCs), technology transfer is considered to be a major possible option for meeting the food security in LDCs (Graves *et al*., 2002). It is also believed that integration of system simulation with field research can facilitate achieving this challenge. In a quest to transfer the scientific knowledge to the non scientific community, International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) was formed in 1982. Decision support System for Agro technology Transfer (DSSAT) is the main product developed by a team of international scientist working under IBSNAT project. This consists of:

- Data management system to store and retrieve the minimum data set of soil, crops, weather and management data to validate and apply the crop simulation models.
- Set of validated crops models to simulate the outcomes of genotype x environment x management interactions
- Application programs that facilitate the manipulation of the databases, the use of crop models, and the presentation and analysis of the model output.

DSSAT is a software system that facilitates the application of crop simulation model in research, teaching, extension, outreach, and policy decision-making (Hoongenboom *et al*., 1999). The use of DSSAT can provide decision maker at all level with much needed information which traditional research cannot meet to understand the possible outcome of their decision and develop plans and policies for achieving goals (Jones and Luyten, 1998). DSSAT models have had the biggest impacts in developing countries in term of theirs applicability, diffusion and adoption among several other models developed so far (Matthews and Stephen, 2002). DSSAT contains a collection of group of crop models for simulating growth and yields like CERES, SOYGRO, PNUTGRO, BEANGRO, SUBSTOR, CROPSIM models.

CERES group consist of wheat, millet, sorghum and maize (Singh *et al.,* 1991). CERES-Rice is built separately because of soil water and nitrogen balance routines and also to simulate the effect of transplanting. CERES model simulate growth by taking into account the following process:

- Phenological development, especially as it is affected by genotype, temperature and day length. The models simulate the timing of panicle initiation and the duration of each major growth stage.
- Extension growth of leaves, stems and roots (morphological development)
- Biomass accumulation and partitioning
- Soil water balance that simulates daily soil evaporation, plant transpiration, runoff, percolation, and infiltration under rainfed and irrigated conditions. Water deficiency affects leaf expansion and, if sufficiently sever, dry matter production.
- Soil nitrogen transformations associated with mineralization/ immobilization, urea hydrolysis, nitrification, denitrification, ammonia volatilization N uptake and use by the crop, and losses of N associated with runoff and percolation. N limitations affect leaf area development, tillering, photosynthesis, and senescence of leaves during grain filing.

Matthews and Stephen (2002) categorized application of CERES-Rice model of DSSAT package into three groups: tools in research, decision-making and education and training. While Timsina and Humphreys (2003) had summarized the application of CERES models into seven groups, such as yield forecasting, yield gap analysis, yield trend analysis, devising agronomic management strategies, extrapolation to other location, impact of climate change on yields, prediction of greenhouse gas emissions, pest and disease management and aiding government policy and strategic planning.

Saseendran *et al*. (1998) had used CERES-Rice model to determine the optimum planting date for rice in southern province of Kerela, India. Similarly, Hundal and Kaur (1999) had used the CERES-Rice model to evaluate the age of rice seedling, number of seedling per hill and plant population for rice growing in Northern Province of Punjab, India. Another important use of CERES- Rice model is to analyze yield gap. Timsina *et al.* (2004) said that it can be used to estimate yield potential and yield gap at site, region and national level and identify reasons for gaps and evaluate management practices to close the gaps. Jintrawet (1995) had used CERES-Rice to compare long term yields with simulated yield for province in north and northeast Thailand. CERES-Rice is also used for yield forecasting, yield trend analysis, devising agronomic management strategies, extrapolating results to other locations, evaluate impact of climate change on yields, to predict green house gas emission especially methane, simulate effect of pest and diseases and help government to formulate policy and strategies. Summary of use of CERES-Rice Model by different scientist in Asia for various purposes are briefly shown in Table 2.5.

Table 2.5: Summary of application of CERES-Rice in Asia.

Application type	Country	References
Yield gap/trend analysis	Thailand, Philippines, southern Vietnam, Nepal, India	Jintrawet (1995); Pinnschmidt, *et al.* (1997); Timsina, *et al.* (1996, 1997); Saseendran, *et al*. (1998 a,b); Sherchand (1998); Aggarwal *et al*. (2000a) Boonjung (2000); Pathak, *et al*. (2003)
Strategic decision making and planning	Bangladesh, India, China, Philippines	Buresh, *et al*. (1991); Sing and Thornton (1992); Timsina *et.al.* (1998); Heng, *et al*., (2000)
Tactical management strategies	India, Nepal, Bangladesh,Philippines, Thailand	Sing and Thornton (1992); Timsina, *et al.*(1995, 1997)
Climate Change Studies	Bangladesh, China, India, Indonesia, Japan, Philippines, Thailand	Bachelet, *et al*. (1993); Bachelet and Gray (1993); Sing and Ritchie (1993); Baer, *et al*. (1994); Karim, *et al*. (1994); Luo, *et al*. (1995); Sing and Padilla (1995); Buan, *et al*. (1996); Tongyai (1994); Seino (1994, 1995); Zhiqing, *et al*., (1994, 1995) Amien, *et al.* (1996); Hundal and Kaur (1996); Timsina, *et al*. (1997); Hundal, *et al*. (1998); Lal, *et al*. (1998); Saseendran, *et al*. (2000); Aggrawal and Mall (2002)
Prediction of green house gas emission	China, India Indonesia	Matthews, *et al*. (2000c); Grace (2002)
Pest and Diseases Management	Philippines, Thailand, Vietnam	Pinnschmidt, *et al*. (1990, 1995)
Aiding Government Policy	Indonesia, Taiwan, India	Chou and Chen (1995); Amien, *et al*. (1996); Aggrawal, *et al*. (2000b)

(Source: Timsina and Humphreys, 2004).

2.8 Weather generator, WGEN

Weather generators are frequently used to provide weather data when the historical data is inadequate or when future data are required (Soltani and Hoogenboom, 2003). Weather generators are widely used in different fields like airports meteorology, environment and civil engineering and agriculture planning and risk management. Weather generator, WGEN (Richardson and Wright, 1984) is an effective USDA program that produces statistically reliable sets of daily values of precipitation, air temperatures and solar radiation for process up to 100 years. A reliable source of weather data is a factor of major importance for decision making and enterprise planning in agriculture.

To generate sets of weather variables for specific location, weather generator use site specific parameters of weather distribution. Weather parameters required for WGEN (Wilkens, 2004) to generate weather are given:

Table 2.6: WGEN parameters.

Acronym	Description
MTH	Month (1 - January, 2 - February, etc.).
SDMN.	Mean daily solar radiation on dry days, MJ/m^2 /day
SDSD	Standard deviation of solar radiation on dry days.
SWMN	Mean daily solar radiation on wet days, MJ/m^2 /day.
SWSD.	Standard deviation of solar radiation on wet days
XDMN	Mean daily maximum temperature on dry days, ^{0}C.
XDSD	Standard deviation of maximum temperature on dry days.
XWMN	Mean daily maximum temperature on wet days, ^{0}C.
XWSD.	Standard deviation of maximum temperature on wet days
NAMN	Mean daily minimum temperature, ^{0}C.
NASD	Standard deviation of minimum temperature.
ALPHA	Alpha coefficient of gamma distribution for rainfall.
RTOT.	Total rainfall, mm

(Source: ICASA, 2003)

These parameters have to be observed in advance from long sets, at least 15-20 years, of historical weather records for the site. The mathematical procedure of weather generator assure that the monthly averages of number of rain events, total monthly precipitation, mean monthly temperature of generated dataset are equal or very close to those that are observed for the site.

2.9 Effect of nitrogen on rice production

Nitrogen is one of the important inputs in rice production (Balasubramanian *et al.,* 1999). Sufficient nitrogen during establishment and tillering ensures adequate tiller per unit area. Nitrogen prior to panicle initiation improves panicle size. It was also found that broadcasting of nitrogen in the standing water at 10-15 days after transplanting causes high N losses (De Datta, 1985). Harre and White (1985) also mentioned that nitrogen is more frequently use in modern agriculture and it is also the nutrient that most often limits crop yield.

However, application of nitrogen is not always in increasing return, its response follows a diminishing return function with increasing nitrogen application. Yield would decrease due to increase lodging and high incidence of pest and diseases (Price and Balasubramanian, 1998). Stanford and Legg (1984) also reported that extra nitrogen or luxury consumption does not result in any yield benefit. Therefore, CERES-Rice model, can be use to explore different nitrogen requirement across wide cropping practices, soil type and weather condition (Bowen and Baethgen, 1998).

2.10 Model validation

Validation is the process of comparing simulated results to real system data not previously used in any calibration or parameter estimation process. The purpose of validation is to determine if the model is sufficiently accurate for its application as defined by objectives of the simulation study (Jones *et al.,* 1998). Model validation is a process to ensure the agreement between the models simulated output and observed data from the real system. Lemon (1977) also defined the validation as comparison of a verified model to the real world and determining if it is suitable for its intended purpose. Assessment of the accuracy of a model involves comparison of output from the model against a set of independent observations (measurement) made on the variables incorporated in the model. An estimate of the model accuracy can be derived through some measured of the average (mean) difference between the observed and modeled values for those variables. The RMSE (Root Mean Square Error) is one such commonly used estimate. RMSE had been used to validate simulation models including DSSAT (Kobayashi and Salam, 2000; Hoogenboom *et al*., 1999). Mean error also termed as mean difference (Garrison *et al*., 1999) is used to identify whether predictions tend to over estimate or under-estimate results compared to measured data (Yang and Huffman, 2004).

For comparison of the difference between estimated parameters and field-measured values, Willmott (1982) described MAE (equation 2.1) and RMSE (equation 2.2) as "among the best overall measures of model performance", of which RMSE is more sensitive to extreme values

$$\text{MAE} = 1/\text{N} * \sum_{i=1}^{N} \left| P_i - O_i \right| \quad [2.1]$$

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(P_i - O_i \right)^2} \quad [2.2]$$

Where:

MAE: Mean Absolute Error
RMSE: Root Mean Square Error
Pi: Predicted value
Oi: Observed value
N: Number of observation

due to its exponentiation; it therefore can be considered as a high estimate of the actual average error (Oxana *et al*., 2004).

Another statistical means to validate the model is use of index of agreement. The index of agreement (Willmott, 1981) is a standardized measure of the degree to which a model's predictions are error free (equation 2.3).

$$d=1-\left[\sum_{i=1}^{N}\left(P_i-O_i\right)^2 / \sum_{i=1}^{N}\left(\left|P_i^1\right|+\left|O_i^1\right|\right)^2\right] \qquad [2.3]$$

Where:

d: Index of Agreement

Pi: Predicted value

Oi: Observed value

N: Number of observation

Index of Agreement also know as d-stat varies from 0.0 (poor model) to 1.0 (perfect model), he also stated that d-stat represent the ratio between the mean square error and the potential error. Potential error is defined as the sum of the square absolute values of the distance from P*i* to O to O*i* and represents the largest value that can attain for each observation/model simulation pair.

2.11 Yield gap analysis

Yield gap analysis is a procedure which aims to establish differences in yield level and identify those factors responsible for these differences. Important role of crop model is the estimation of potential yield and yield gaps at site, region and national levels, identification of reason for the gaps, and evaluation of management option for closing those gaps (Timsina *et al.*, 2004). Analysis of yield gaps in crop production is facilitated by using the concept of production ecology where different sets of ecophysiological variables affecting crops growth and development are distinguished. The approach recognizes three set of factors namely, yield defining or determining, yield limiting factors and yield reducing factors (Lansigan, 1998; Caldiz *et al*., 2002). Yield determining factors are day length, solar radiation, temperature, carbon dioxide, and cultivars. Generally we cannot modify these factors except developing new varieties suitable and yield more under the existing environment. Next and the important yield limiting factors are water and nutrient. These can be modified by grower through cultural practices such as application of inputs (Caldiz *et al*., 2002) and then determine the gap between potential and attainable yield. Lastly, the yield reducing factors are diseases, weeds and pest. These factors determine the gap between attainable and actual yields.

Yield gaps are interpreted in many ways, but for the purpose of this study yield gaps are calculated as the differences among potential yield, experimental yield and farm yield. Simulated potential yield in this context is defined as the maximum yield which could be reached by a crop in a given environment, as determined, for example, by simulation models (DSSAT v4) without any stress of water and nitrogen. Experimental yield is defined as yield achieved at experimental station with no physical, biological and economical constraints and with best-management practices at given time and ecology. Similarly, farm yield is define as the average farmers yield in a given target area at a given time and in given ecology (Tran, 2001).

Crop simulation models have proved to be useful in rice research and development for some years. IRRI also highlighted that modeling is especially useful in yield analysis. From yield gap analysis, constraints that can be reduced can be identified so researcher can concentrate on overcoming those factors that contribute to the gap between farm yield, potential yield and experimental yield. One such model used for rice yield gap analysis is CERES-Rice, available with DSSAT v4 package (Timsina *et al*., 2003). Jintrawet (1995) had used CERES-Rice to compare long-term yield difference in northern and northeast Thailand. Simulated yield were more than the observed yield by 0.4 t/ha in north and 1.0 t/ha in northeast due to damaged caused by pest, diseases, rodent and lodging. Similarly, using CERES-Rice model, Saseendran *et al*. (1998) estimated potential yield of high yielding cultivar Jaya across four planting date and compare it with average actual farm yield under rain fed and sub optimum nitrogen management in Kerala, India. He found large gap and attribute the gap to lack of water and suggested storage of surplus rainwater during rainy season for irrigating crops during the dry season.

Timsina *et al*. (2004) mentioned that CERES-Rice can be used to identify yield gap between potential, on-station, and on farm and continued saying it is efficient in the sense of resource utilization and sustainability.

2.12 Factors causing yield gaps

Several factors cause yield gaps in rice. In general, the factors causing yield gaps could be classified as (Tran, 2001);

i. Biophysical: Climate/weather, soil, water, pest pressure, weeds

ii. Technical/agronomic: tillage, variety/seed selection, water, nutrient, weeds, pests and post harvest management.

iii. Socioeconomic: Socio/economic status, farmers tradition and knowledge, family size, household income/expenses/investment

iv. Institutional/policy: government policy, rice price, credit, input supply, land tenure, market, research, development, and extension.

v. Technology transfer and linkages: competence and equipment of extension staff, research, development and extension integration, farmers' resistance to new technology, knowledge and skills, weak linkages among public, private, and nongovernmental extension staff.