# GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF DROUGHT TOLERANT RICE CULTIVARS UNDER DIFFERENT CROP MANAGEMENT PRACTICES:SIMULATION USING CSM-CERES-RICE MODEL IN CENTRAL TERAI OF NEPAL

**BISHAL DHAKAL**

**MARCH 2016**

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**BISHAL DHAKAL**

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## CERTIFICATE

This is to certify that the thesis entitled "**GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF DROUGHT TOLERANT RICE CULTIVARS UNDER DIFFERENT CROP MANAGEMENT PRACTICES:SIMULATION USING CSM-CERES-RICE MODEL IN CENTRAL TERAI OF NEPAL"** submitted in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN AGRICULTURE** with major in **AGRONOMY** of the Postgraduate program, Institute of Agriculture and Animal Science, Rampur, is a record of original research carried out by **Mr. BISHAL DHAKAL** Id. No. **R-2013-AGR-05M**, under supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

Mr. Lal Prasad Amgain, Ph. D.
Assistant Professor and Chairman
Advisory committee
Date:

The thesis attached hereto, entitled **“GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF DROUGHT TOLERANT RICE CULTIVARS UNDER DIFFERENT CROP MANAGEMENT PRACTICES:SIMULATION USING CSM-CERES-RICE MODEL IN CENTRAL TERAI OF NEPAL”** prepared and submitted by **Mr. BISHAL DHAKAL,** in partial fulfillment of the requirements for the degree of Master of Science in Agriculture **(AGRONOMY)**, is here by accepted.

Mr. ChintanManandhar
Member, Advisory Committee
Date:

Prof. Narendra Kumar Chaudhary
Member, Advisory Committee
Date:

Asst. Prof. Lal Prasad Amgain, Ph. D.
Chairman, Advisory committee
Date:

Accepted as partial fulfillment of the requirements for the degree of Master of Science in Agriculture (Agronomy).

Prof. Gopal Bahadur K.C., Ph.D.
Assistant Dean (Academics)
Postgraduate Program
Date:

Prof. Narendra Kumar Chaudhary
Dean
Institute of Agriculture and Animal Science
Date:

# DEDICATED TO

# MY
# BELOVED PARENTS

**(MUKUNDA PRASAD DHAKAL AND KALPANA DHAKAL)**

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Bishal Dhakal

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| | |
|---|---|
| % | Percent |
| @ | At the rate of |
| $^0C$ | Degree Celsius |
| cm | Centimeter |
| CON | Conventional |
| CV | Coefficient of Variance |
| DAP | Diammonium phosphate |
| DAS | Days After Seeding |
| DAT | Days After Transplanting |
| DLL | Drained lower limit |
| DMRT | Duncan's Multiple Range Test |
| DSSAT | Decision Support System for Agrotechnology Transfer |
| DUL | Drained upper limit |
| *et al.* | And others |
| g | Gram |
| g $cm^{-3}$ | gram per cubic centimeter |
| GDD | Growing Degree Days |
| GDP | Gross Domestic Product |
| GY | GY |
| HUE | Heat Use Efficiency |
| i.e. | That is |
| ICM | Integrated Crop Management |
| Kg $ha^{-1}$ | Kilogram per hectare |

| | |
|---|---|
| LAI | Leaf Area Index |
| LSD | Least Square Difference |
| m | meter |
| masl | meter above sea level |
| Mg | Mega gram |
| mm | millimeter |
| MOP | Murate of potash |
| mt | metric ton |
| N | Nitrogen |
| $NH_4^+$ N | Ammonical nitrogen |
| $NO_3^-$ N | Nitrate nitrogen |
| PI | Panicle initation |
| PM | Physiological maturity |
| ppm | Parts per million |
| SEm (±) | Standard Error of Mean |
| SRI | System of Rice Intensification |
| t $ha^{-1}$ | Tonne per hectare |
| VDC | Village Development Committee |

**ABSTRACT**

Name: BishalDhakal ID No. R-2013-AGR-05M
Semester and year of admission: $1^{st}$, 2013 Degree: M. Sc. Ag.
Major subject: Agronomy Department: Agronomy
Major advisor: Ass. Prof. Lal Prasad Amgain, Ph. D.

A field experiment and simulation study were carried out to evaluate CSM-CERES-Rice ver. 4.5 for its ability to simulate agronomic and climate change parameters of drought tolerant rice cultivars under different crop management practices under humid sub-tropical climate of Nawalparasi during rainy season of 2014. The experiment was laid out in strip plot design with three replications consisting four drought tolerant rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) and three crop management practices (SRI, ICM and conventional). Soil of experimental field was loam in texture, whereas initial content of N was medium in surface horizon and lower in sub surface horizon. The soil available P and K was high in surface horizon and medium in sub-surface horizon. Significantly higher grain yield of rice was recorded in SRI (5.28 t $ha^{-1}$) than conventional (4.49 t $ha^{-1}$), but was at par with ICM (4.73 t $ha^{-1}$), whereas cultivars did not have significant influence in grain yield. Growth and yield attributes like LAI, dry matter accumulation, effective tillers per square meter and filled grain per panicle were positively correlated with grain yield (r =0.46, 0.72, 0.75 and 0.91, respectively). Sukkhs-5 required the maximum days to reach panicle initiation (61 DAS), heading (83 DAS) and physiological maturity (115.67 DAS). Similarly, conventional practice required the maximum days to reach panicle initiation (60.50 DAS), heading (81.25 DAS) and physiological maturity (115.50 DAS). Sukkha-5 required the maximum GDD to reach panicle initiation (1431.32°C), heading (1909.20°C) and physiological maturity (2567.36°C). Similarly, conventional practice required the maximum GDD to reach panicle initiation (1459.44°C), heading (1915.24°C) and physiological maturity

(2622.83°C). The HUE was significantly higher in SRI practice (2.25) than ICM (1.93) and conventional (1.71) practices. The minimum cost of cultivation (NRs. 88,005.68ha$^{-1}$) and the highest gross return (NRs.144652ha$^{-1}$), net return (NRs. 56647ha$^{-1}$) and B:C ratio (1.64:1) was recorded in SRI practice.The model calibration was performed with four rice varieties (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) with high yielded SRI crop management practice. The determined genetic coefficients for Sukkha-3 were: 470 (P1), 160 (P2R), 470 (P5), 12 (P2O), 96 (G1), 0.050 (G2), 1.09 (G3) and 1.0 (G4). For Sukkha-4: the same values were 410 (P1), 160 (P2R), 500 (P5), 12 (P2O), 97 (G1), 0.028 (G2), 1.09 (G3) and 1.0 (G4). Genetic coefficient for Sukkha-5 were 560 (P1), 160 (P2R), 440 (P5), 12 (P2O), 94 (G1), 0.040 (G2), 0.98 (G3) and 1.0 (G4). Similarly, genetic coefficient for Hardinath-2 were 200 (P1), 180 (P2R), 540 (P5), 11.8 (P2O), 96 (G1), 0.070 (G2), 0.8 (G3) and 1.03 (G4). The perfectly matched resultant values from model evaluate output on parameters like days to anthesis (RMSE=2.525, d-stat =0.956 and $R^2$=0.895), days to physiological maturity (RMSE=2.55, d-stat =0.925 and $R^2$=0.839), grain yield (RMSE=1504.495, d-stat =0.307 and $R^2$=0.545) and tops weight at maturity (RMSE=3715.596, d-stat =0.283 and $R^2$=0.531) authenticated the validation of model. The model was found sensitive to weather years, transplanting dates and various parameters of climate change and noticed the various changes for different cultivars on crop yields. The simulated yield for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 was reduced by 8.34%, 6.63%, 28% and 8.04%, respectively in 2012. In the year 2008, Sukkha-5 produced 22.88% lesser yield than standard. For Sukkha-3, Sukkha-4,Sukkha-5 and Hardinath-2, there were 22.01%, 22.26% 63.11% and 53.22%yield decline, respectively when one month delay (4$^{th}$ August) of transplanting. The grain yield was increased by 2.48% and 5.44% in one month early transplanting (4$^{th}$ June) for Sukkha-4 and Sukkha-5, respectively. Change in temperature (- 4$^{0}$C ), $CO_2$ concentration (+20 ppm) with change in

solar radiation (+1MJ $m^{-2}$ $day^{-1}$) resulted maximum increase in yield of Sukkha-3, Sukkha-4and Hardinath-2 by 3.86%, 1.45% and 1.68%, respectively, while the maximum increase in yield for Sukkha-5 was 0.58% with change in temperature (- $4^0$C), $CO_2$ concentration (+20 ppm),and solar radiation (-1MJ $m^{-2}$ $day^{-1}$). The maximum decrease in yieldof Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2was recorded by 20.07%, 51.22%, 22.07% and 75.25%, respectively when the change in temperature (+$4^0$C), $CO_2$ concentration (+20 ppm) and solar radiation (-1MJ $m^{-2}$ $day^{-1}$). Results showed that the crop model would be a precision agriculture tool for extrapolation of the allocation of agronomical resources.

Ass. Prof. Lal Prasad Amgain, Ph. D.
Major Advisor

BishalDhakal
Author

# 1 INTRODUCTION

Rice (*Oryza sativa* L.), belonging to Poaceae family, is a staple food for more than half of the world's population (Delseny *et al.*, 2001; Feng *et al.*, 2013). It is among the most valuable crops with long plantation history and now it is considered as important food products throughout the world (Sabetfar et. al., 2013). Rice plantation is the oldest agriculture in Asia and supplies more than 80 % of calorie and 75 % of protein consumed by people of this continent (Rabiey, 1996). About 90% of global production of rice is in Asian region, home to 60% of the world's population (IRRI, 2013), where about 95% of the global rice production is consumed (Alam *et al.*, 2009). Globally, the rice area harvested has increased only marginally from 120.1 million ha in 1960 to 155.7 million ha in 2008 where as the average rice yield has tripled from 1.84 to 4.25 Mg ha $^{-1}$ during the same period (Childs and Baldwin, 2010). The estimate of world paddy production in 2011 is $7.2 \times 10^8$ ton (FAOSTAT, 2010). It is grown from sea level (Indonesia) to more than 3050 m elevation (Nepal) and from 50°N latitude to 40°S latitude from equator.

Rice is a staple food of Nepalese people, accounting about 43 % area and about 53% of the total production under cereals in the country. In Nepal, the share of agriculture and forestry for national gross domestic product (GDP) is 33.03% on which rice alone contributes 20.75% of the agriculture gross domestic product (AGDP) and 10.2% of total GDP (Poudel, 2011). It is grown in about 1.42 million hectares with total production about 4.50 million tons and 3.17 t ha$^{-1}$ productivity (MoAD, 2013). It ranks first crop for both acreage and production and it's production amounts to half of the total cereal grains produced in the country (Ghimire *et al.*, 2013). It contributes to at least six months of engagement for 75 percent of the working population in Nepal. Furthermore, rice provides nearly 50 percent of the calorie requirements supplied by cereals and contributes 38.5%

dietary energy, 29.4% protein and 7.2% of fat for Nepalese people (FAOSTAT, 2004). Rice straw and by-products provides about 32-37% of total digestible nutrient for livestock, mainly in dry season (NRRP, 1997).

Available decadal data on rice yield indicates changes in the average national rice yields from 1.80 t $ha^{-1}$ during 1960s, 2.41 t $ha^{-1}$ in 1990/91, 2.70 t $ha^{-1}$ in 2000/01, 2.98 t $ha^{-1}$ in 2010/11 and ultimately 3.17 t $ha^{-1}$ in 2012/13 (MoAD, 2013). It indicates the increasing trend in productivity of rice. But, when rigoursly visualizing the data of recent years, the productivity of rice was 2.98 t $ha^{-1}$ in 2010/11, 3.31 t $ha^{-1}$ in 2011/12 and 3.17 t $ha^{-1}$ in 2012/13 (MoAD, 2013). It indicates the decline of productivity in recent years which might be due to drought occurrence during the growth period of rice.

Rice also ranks first in area and production among cereals in western-central terai. It is grown in about 186 thousand hectares with production about 703 thousand tons (MoAD, 2013). It is the major crops of western-central terai where the drought is causing lesser yield than the eastern and mid-central terai districts.

Climate change includes gradually increasing average temperature as well as increased frequency and magnitude of extreme weather events (Mirza, 2003). The change in the atmospheric composition of gases is attributed to anthropogenic emissions of green house gases such as $CO_2$, $CH_4$, $N_2O$ and other gases. The inter-governmental panel on climate change (IPCC) has projected that the global mean surface temperature is predicted to rise by 1.1–6.4$^0$C by 2100 with the different amplitudes of temperatures and $CO_2$ for different scenarios of 2020, 2050 and 2080 (IPCC, 2007). There will be increase in mean temperature by 0.4 to 2.0 $^0$C in monsoon and 1.1- 4.5 $^0$C in winter by 2070 (IPCC, 1996). The temperature has increased by 0.04 – 0.06 ºC annually on an average in Nepal (MoE, 2010). Increased temperature may decrease rice potential yield up to 7.4% per degree increment of temperature (Murdiyarso, 2000). Rice is also an important crop of the central-terai zone in Nepal, where farmers have complained over the years about increasing difficulty to plant rice in June-July due to delayed monsoon, because about 60% rice area in Nepal is still rainfed. Rice productions rely on ample water supply and thus are more vulnerable to drought stress than other crop. Changing in rainfall pattern and distribution is negatively affecting paddy production in Nepal. Fail to raise nursery on time, use of old seedling due to untimely rainfall, irrigation problem, plant protection problems, harvesting problems are some of the issuable problems faced by farmers in recent days due to climate change. Climate change influences the plant life in many ways and can inhibit, simulate, alter or modify crop performance. Its component (temperature, solar radiation, rainfall, relative humidity and wind velocity) independently or in combination, can influence crop growth and productivity. Increasing maximum and minimum temperature, irrespective of whether the $CO_2$ concentration increased or not, seemed to be adverse effect on rice yield (Amgain, 2004). The recently appeared climatic adverseness like increase in ambient $CO_2$ concentration, increase or decrease in rainfall amount and intensity, change in solar radiation including global dimming, temperature variations and variations in relative humidity etc. as a whole is negatively affecting the crop growth and yield in general (Malla, 2008).

Besides these, several factors like drought, weeds, low factor productivity and reducing resource use-efficiency due to deteriorating soil health are causing the lower productivity of rice in Nepal. Among various methods for the climate change adaptation in rainfed areas, proper selections of resource conservation technologies like (SRI, ICM, etc.) (Islam *et al.*, 2014b) and drought tolerant rice cultivars (Basnet, 2015) are important management factors determining yield of rice. Drought tolerant rice cultivars are released over the years, but their adoption by farmers, and their proper agro-climatic requirements in accordance to crop physiology and management conditions in major rice production domains of Nepal has not been explored yet. Moreover, the rice production technologies reported till now are conventional (farmers' practices). System of Rice Intensification (SRI) and Integrated Crop Management (ICM) are recently developed rice production practices. Little bit work has been done on SRI, but ICM is totally a new technology in Nepal, which is hybrid in between SRI and conventional methods.

A range of technologies has been identified in recent years, which have the potential to increase resource use efficiency, reduce adverse environmental impacts, and increase crop productivity in Asia. It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. Among several models evolved, the Decision Support System for Agrotechnology Transfer (DSSAT) is pioneer one. DSSAT was originally developed by an international network of scientists; cooperating in the International Benchmark Sites Network for Agro technology Transfer (IBSNAT) project (Jones *et al.*, 1998; Iyanda *et al.*, 2014; Kaur *et al.*, 2015; Anar *et al.*, 2015). The IBSNAT suites of crop models represent many of the major staple food crops and have been widely calibrated and validated in many countries. DSSAT ver. 4.5 is one crop simulation model which can help to investigate a range of issues from crop management (Jones *et al.*, 2003). It simulates growth, phenology, yield and development activities under different management practices and climate change scenarios.

Cropping system model (CSM-CERES Rice) is a decision support tool used widely to evaluate and/or forecast the effects of environmental conditions, management practices, and different genotypes on rice growth, development and yield (Jones and Kiniry, 1986). DSSAT ver. 4.5 crop model and CSM-CERES-Rice is a mechanical model having the capacity of predicting growth, phenology, yield and climate change simulations over the world and it's applicability has been tested in Nepal.

In this regard, CERES-Rice is a process-based, management-oriented model that can simulate the growth and development of rice as affected by varying levels of water and nitrogen (Ritchie *et al.*, 1998). The model can identify the gaps between potential and on-station and on farm yields, and also helps to evaluate management option and determine likely environmental impacts. They can also be used to forecast yield prior to harvest and extrapolate the results conducted in one season or location to other seasons, locations or management.

Earlier versions of the DSSAT model (ver. 3.5, ver. 4.0) have been evaluated across rice growing environments of Asia and Australia and their performance has been generally satisfactory, but variation exists (Timsina and Humphreys, 2003). Although CSM-CERES-Rice has been tested in Chitwan for rice cultivars under graded nitrogen levels and found valid (Lamsal, 2009), but it is not tested for rice cultivars under different management practices. It will be high valued scientific work in Nepal to simulate agronomic and climate change parameter on the growth and yield of the rice by using the model. Therefore present investigation is planned, executed and accomplished with following objectives:

- To assess the growth, productivity and profitability of various drought tolerant rice cultivars as affected by management practices.
- To assess the best agro-climatic indices in relation to phenology of drought tolerant rice cultivars under different management practices in farmers’ field.
- To evaluate the CSM-CERES-Rice model ver. 4.5 under central terai condition.

# 2 LITERATURE REVIEW

## 2.1 Climatic requirement of rice

The temperature requirement for rice ranges from 20-37ºC, but the optimum temperature is around 30ºC for maximum and 20ºC for minimum temperature (Rao, 2008). The favorable temperature for physiological process of rice is 15-33ºC. The optimum temperature for vegetative growth of rice is generally from 12-38ºC, with an optimum between 25-30ºC (Horie *et al.*, 2000). During reproductive stage, temperatures below 20ºC or above 35ºC particularly at flowering generally results in increase in spikelet sterility (Horie *et al.*, 2000). The optimum temperature for ripening is 26ºC. Further, rice requires seasonal total of at least 2400 ºC GDD from seedling to the harvest (Horie *et al.*, 2000).

The water requirement of rice varies according to the cultivars, management practices and many other factors. Rice grown under SRI management practices requires less water than conventional practices (Geethalakshmi *et al.*, 2011; Mohanty *et al.*, 2014). Similarly, drought tolerant rice cultivars can complete its life cycle in less water than other cultivars. However, rice cultivation can be done in the areas with minimum annual average rainfall of 1150 mm, but the optimum areas are those having annual rainfall of 1750-3000 mm.

The solar radiation plays an important role in rice production. The higher the solar radiation intensity, the greater is the yield of rice. Primarily rice is short day plant requiring day length of about 10 hours. Thus long day can prevent considerably delay flowering (Vergara and Chang, 1985). In rice plant, the most critical period of solar energy requirement is from panicle initiation stage to before maturity stage.

Too higher or lower relative humidity is inversely related to grain yield of rice. The photosynthesis of rice leaves reaches the maximum at relative humidity of 50-60% and above this range decrease slowly with increasing humidity. Higher humidity subjects unusual stress which favors the spread of fungal and bacterial diseases (Rao, 2008). Relative humidity more than 90% during vegetative phase and below 90% during anthesis is acceptable.

Gentle wind is proportional to higher grain yield. Gentle winds transports $CO_2$ to the leaf canopy, but strong wind causes severe damage and may lead to sterility due to pollen dehydration, spikelet sterility and abortive endosperms (Rao, 2008).

## 2.2 Management practices of rice

Different management practices have been practiced in the world for the cultivation of rice. Among them, SRI and ICM are new management practices whereas conventional practice is the old management practice.

### 2.2.1 System of Rice Intensification (SRI)

The "System of Rice Intensification", developed in 1983 by the French Jesuit Father Henri de Laulanié in Madagascar (Laulanié, 2011; Wu *et al.*, 2015), was mainly developed through participatory on-farm research (Dobermann, 2004) and is a new technique for rice culture (Mahajan and Sarao, 2009). It has been proposed as an integrated and agro-ecologically sound approach to rice cultivation (Dobermann, 2004). It is a budding science, more labor intensive and requires proper care. It permits resource-limited farmers to realize higher yields with greatly reduced rates of irrigation, seed rate and without external inputs (Stoop *et al.*, 2002, Wu *et al.*, 2015). The increase in grain yield under SRI has been reported from 5 % to as high as 300 % in Nepal, Myanmar, Srilanka and Indonesia compared to conventional management practice (Uphoff, 2007 b). Besides these, it also offers benefits including cost reduction and resistance to biotic and abiotic stresses (Kassam *et al.*, 2011; Uphoff, 2012). It is claimed to be a novel approach to rice cultivation that is both more productive and more sustainable than conventional methods (Glover, 2011).

SRI is based on six principles: (i) transplanting young seedlings (8-15 days old), (ii) transplanting single seedlings, (iii) providing wider spacing between plants, (iv) application of organic matter for fertilization in preference of chemical fertilizer, (v) soil aeration through mechanical weeding, and (vi) reduction of irrigation water application, keeping soils moist but not flooded (Uphoff, 2007a; Styger *et al.*, 2011).

SRI changes the management of rice plants, and of the soil, water and nutrients that support them, in simple but specific ways to create optimal growing environments for rice plants so that their genetic potentials are better expressed (Satyanarayana *et al.*, 2007). It is based on certain insights about how rice plants can be induced to become more productive, particularly by (a) elicting greater root growth, which is visible, and (b) enhancing soil biotic activity, which is not visible (Satyanarayana *et al.*, 2007). Moreover, SRI concepts and practices have also been extrapolated for application to rainfed rice production and to other crops (Abraham *et al.*, 2014).

### 2.2.2 Integrated Crop Management (ICM)

Integrated Crop Management is a common sense approach to farming that can be thought of as a means of production, which falls somewhere between conventional production and organic production, with one of the prime objective of reduction or replacement of external farm inputs such as inorganic fertilizers, pesticides and fuel, by means of farm produced substitutes and better management of inputs (Kumar and Shivay, 2008). It combines the best of traditional methods with appropriate modern technology, balancing the economic production of crops with positive environmental management (Islam *et al.*, 2014b).

The ICM system in rice seeks to develop a management approach at farm level that manages the growing of rice crops as a total production system, taking into account all factors affecting yield and quality (Nguyen, 2002). It takes into account the interactions and interdependencies among management technologies (Mariano *et al.*, 2012). It also provides a framework that helps farmers to evaluate their management skills and to recognize their strengths and weaknesses in order that the management of subsequent rice crops may be improved (Clampett *et al.*, 2003).

Rice Integrated Crop Management recognizes that rice growing is a production system involving many component factors that must be managed to achieve potential yields (Singh *et al.*, 2007) and can provide the basis for improving practices (Kumar and Shivay, 2008). Through integrated crop and resource management, farmers can combine their practices with the new technologies i.e. resources conserving technologies (ADB, 2009). Successful ICM system in rice has potential to improve sustainable increase in crop yields, productivity, grain quality, and at the same time, contribute to environmental conservation (Zhao *et al.*, 2013; Islam *et al.*, 2014a). The yield gap in rice can be narrowed through integrated crop management to improve sustainable rice production, food security and the socio-economic well-being of rice growers throughout the world (Wopereis *et al.*, 2001; Gassner *et al.*, 2013).

An ideal ICM system, appropriate to all conditions of climate, soil, prevailing market forces, and so forth, cannot be developed. However, the aim is to establish principles, know-how and guidelines through which advisers and farmers can devise their own optimum ICM strategies which can range in extremes of ‘near conventional’ to ‘near organic’ (Kumar and Shivay, 2008).

Nevertheless, the ICM system is a complex system (Clampett *et al.*, 2003) that depends heavily on the development, testing and use of a range of new technologies. These include more selective chemical pesticides, more precise application systems, improved biological control methods, disease-resistant crop varieties, more reliable disease, pest, weed and nutritional forecasting and decision-support systems, rapid diagnostic methods for plant diseases, and establishment of habitats for natural enemies of pests (Kumar and Shivay, 2008). Though the net return realized under ICM is high; involvement of more efforts, faith towards traditional practices, ignorance and lack of knowledge on scientific water management has hindered the adoption of ICM in farmers' level (Patel *et al.*, 2008; Islam *et al.*, 2014a).

### 2.2.3 Conventional management practice

Conventional method of rice transplanting is old technology in rice culture. It requires higher seed rate, amount of water and chemical inputs (Wu *et al.*, 2015). In conventional method,, the field is under continuous flooding throughout the growing season (Van Der Hoek *et al.*, 2001). This method sacrifices soil and plant health in order to suppress weed growth, achieved through permanent flooding. Further, conventional method is too inorganic and farmers managed, costly and requires high amount of seeds and planted old age seedling, less productive and suffered with many problems (Lakpale and Shrivastava, 2012). Planting old seedlings closely spaced with constant flooding forces plants to assume a shape and growth pattern that masks their true potential for growth. Thus, the grain yield is also less in conventional method than other methods of rice cultivation (Mohanty *et al.*, 2014; Ahmed *et al.*, 2015). Though this method has low production than other new management approaches like SRI and ICM, farmers' faith towards this method is high and has hindered the adoption of new management approaches (Patel *et al.*, 2008; Islam *et al.*, 2014a).

**2.3 Growing degree days (GDD) and Heat use efficiency (HUE)**

In the absence of extreme conditions such as unseasonal drought or disease, plants grow in a cumulative stepwise manner which is strongly influenced by the ambient temperature. Growing degree days take aspects of local weather into account and allow farmers to predict the plants pace towards maturity. Growing degree days (GDD) is defined as the number of temperature degrees above a certain threshold base temperature, which varies among crop species (Womach, 2005). The base temperature is that temperature below which there is no plant growth.

According to Rajput *et al.* (1987):

$$\text{Growing degree days (GDD)} = \sum_{i=1}^{n} [\frac{(\text{Tmax} + \text{Tmin})}{2} - \text{Tb}]$$

Where, Tmax and Tmin are maximum and minimum temperatures of the day, respectively and Tb is the base temperature for rice crop which is 10 $^{o}$C i.e. below this temperature, there is no crop growth.

Heat is one of component that influence directly to the physiological activities of the plant. Heat use efficiency is directly related with grain yield, other growth factors such as moisture remaining constant. According to Rajput *et al.* (1987), HUE for grain yield was obtained as:

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield}}{\text{Accumulated heat units}}$$

Where grain yield is expressed in kg ha$^{-1}$ and accumulated heat units is expressed in $^{o}$C.

**2.4 Drought**

Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many regions of the world (Passioura, 2007).

According to statistics, the percentage of drought affected land areas more than doubled from the 1970s to the early 2000s in the world (Isendahl and Schmidt, 2006). It is a world-spread problem seriously influencing grain production and quality and with increasing population and global climate change making the situation more serious (Hongbo *et al.*, 2005).

Drought is an abiotic stress, and it affects plants at various levels of their organization. Under prolonged drought, many plants will dehydrate and die. Water stress (drought) in plants reduces the water potential and turgor of plant cell, which elevate solute concentrations in the cytosol and extracellular matrices. As a result, cell enlargement decreases leading to growth inhibition and reproductive failure (Ali *et al.*, 1999), which is followed by accumulation of abscisic acid (ABA) and compatible osmolytes like proline, which cause wilting. It not only affects plant water relations through the reduction of water content, turgor and total water, but it also affects stomatal closure, limits gaseous exchange, reduces transpiration and arrests carbon assimilation (photosynthesis) rates (Razak *et al.*, 2013). Negative effects on mineral nutrition (uptake and transport of nutrients) and metabolism leads to a decrease in the leaf area and alteration in assimilate partitioning among the organs (Zain *et al.*, 2014). It is estimated that more than 50% of the world rice production area is affected by drought (Bouman *et al.*, 2005).

### 2.4.1 Effect on yield and yield attributes of rice

Drought stress during the vegetative growth, flowering, and terminal stages of rice cultivation can cause spikelet sterility and unfilled grains (Kamoshita *et al.*, 2004). Usually, drought during the grain-filling process induces early senescence and shortens the grain-filling period (Plaut *et al.*, 2004). Water stress during vegetative stage reduces tiller number, while stress at the reproductive and grain-filling stage reduces grain number and weight (Sarvestani *et al.*, 2008). Rice is sensitive to water deficit from 20 days before heading (booting stage) up to 10 days after heading (Matsushima, 1962) and the most sensitive stage is about 10 days before flowering until 7 days after flowering (O' Toole, 1982).

**2.4.1.1 Effect on number of tillers and effective tillers per hill**

The number of tiller per hill decreases with decreasing soil moisture level (Zubaer, *et al.*, 2007). However, the reduction in tillers number, under water stress, is less at reproductive stage in comparison to vegetative stage (Bakul *et al.*, 2009). Reduced tiller production under lower soil moisture levels might be the fact that under water stress, plants are not able to produce enough assimilates for inhibited photosynthesis. It may be also happened for less amount of water uptake to prepare sufficient food and inhibition of cell division of meristematic tissue (Zubaer *et al.*, 2007). Significant decrease in number of tillers per hill under moisture stress, at different growth stages, except that at flowering stage was also reported by Rahman *et al.* (2002). Drought before or during tillering reduce the number of tillers and panicle per hill (Bouman and Toung, 2001). The number of effective tillers per hill reduces when the moisture stress is encountered at tillering to panicle initiation stage. However, the number is not affected when the stress is encountered at reproductive stage (Bakul *et al.*, 2009). The poor emergence of panicle under moisture stress condition leads to low number of effective tillers (Ekanayake, 1987).

**2.4.1.2 Effect on panicle length**

Panicle length will decreases due to water stress (drought) at tillering to panicle initiation (vegetative stage) and panicle to grain filling stage (reproductive stage); however, the stress at reproductive phase causes more decrease in the length of panicle (Bakul *et al.*, 2009). Reduced panicle length under moisture stress condition was also reported by Islam *et al.* (1994a).

#### 2.4.1.3 Effect on filled grains per panicle

The number of filled grains per panicle decreases with the moisture stress at tillering to panicle initiation stages and panicle initiation to grain filling stages. Water stress (drought) at panicle initiation to grain filling stage (reproductive stage) is less harmful for filled grains than that of tillering to panicle initiation stage (Bakul *et al.*, 2009). Moisture stress affects the grain formation and gradually increases sterility (Islam *et al.*, 1994a). Water stress (drought) at or before panicle initiation reduces the most potential spikelet number and grains filling stage resulting 40% reduction in the percentage of filled grains (RRDI, 1999).

#### 2.4.1.4 Effect on sterility

Water stress during reproductive stage increased sterility percentage (Yambao and Ingram, 1988). Moreover, water stress (drought) after flowering increased the no. of empty spike lets per panicle (Begum, 1990).

#### 2.4.1.5 Effect on thousand grains weight

Thousand grains weight also decreases when the crop is subjected to drought at different stages of growth. Stress during grain filling stage decreases grain weight (RRDI, 1999). Moreover, water stress after flowering (Begum, 1990) and during grain filling stage reduces the weight of individual grain (O'Toole *et al.*, 1979).

#### 2.4.1.6 Effect on yield

Drought induces yield reduction which depends upon the severity and duration of the stress period. The prevailing drought reduces plant growth and development, leading to hampered flower production and grain filling and thus smaller and fewer grains. Moreover, drought decreases the seed-filling duration, leading to smaller seed size (De Souza *et al.*, 1997). Drought following flowering is known to have little effect on seed-filling rates, but seed-filling duration is shortened leading to small seed size or seed yield (Wardlaw and Willenbrink, 2000).

Evaluating the effect of different durations of water stress (drought) at various growth stages showed that water stress at any stage would reduce yield (IRRI, 2002). Grain yield is reduced dramatically in all varieties with drought starting at panicle initiation or at flowering. Water stress at flowering reduces grain yield more, resulted from the reduction in fertile panicle number and filled grain percentage (Sarvestani *et al.*, 2008). Drought stress that developed prior to flowering, generally delays the time of flowering and the delay in flowering is negatively associated with grain yield, fertile panicle percentage and filled grain percentage (Pantuwan *et al.*, 2002).

Yield losses resulting from water deficit are particularly severe when drought strikes at booting stage (Islam *et al.*, 1994b). The mild stress of drought during reproductive stage reduces yield up to 92% whereas severe stress at this stage reduces the yield up to 94% (Lafitte *et al.*, 2007). Similarly, the yield reduces by 30-45% and 60% in grain filling stage due to mild and severe drought respectively (Basnayake *et al.*, 2006). However, the duration of these stresses was more closely related to yield reduction than to stage at which the stress occurred. During the reproductive phase, water deficit of 5-10 days reduce yield by 25-45% and water deficit of 15 days reduced yield up to 88% (Boonjung and Fukai, 1996).

### 2.4.2 Response of drought tolerant cultivars to drought

Drought tolerance refers to the degree to which a plant is adapted to arid or drought conditions. Plants tolerant to drought have several drought tolerance mechanisms. Dehydration avoidance, enhanced capture of soil moisture, reduced water use, osmotic adjustment and conserved cellular water content, dehydration tolerance, delayed senescence or stay green are some mechanisms of plants tolerant to drought (Blum, 2005).

Further, drought tolerant plants typically make use of either $C_4$ carbon fixation or Crassulacean Acid Metabolism (CAM) to fix carbon during photosynthesis. Drought tolerant cultivars of rice are developed through crossing drought-tolerant donors with high-yielding, drought-susceptible cultivars and conducting direct selection for yield under drought (Kumar *et al.*, 2008). Several drought tolerant QTLs have included in these cultivars which helps for panicle initiation and heading even in drought condition (Chaudhary, 2015). These QTLs helps for drought tolerance and give production even in drought condition. Drought tolerant rice cultivars, therefore, have shown relatively high and stable yield across a range of stress-prone and irrigated environments (Anantha *et al.*, 2015). Further, these cultivars also have other QTLs that make them tolerant to several other biotic and abiotic stresses (Anantha *et al.*, 2015; Chaudhary, 2015).

**2.5 Climate and climate change**

Climate is a measure of the average pattern of variation in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle count and other meteorological variables in a given region over long periods of time. Climate is different from weather, in that weather only describes the short-term conditions of these variables in a given region.

Climate change refers to a persistent change in the mean and variability of climate parameters (temperature, rainfall, humidity and soil moisture) due to change in composition of the atmospheric gases. It is a phenomenon due to emissions of greenhouse gases from fuel combustion, deforestation, urbanization and industrialization resulting variations in solar energy, temperature and precipitation (Upreti, 1999). Climate change includes gradually increasing average temperature as well as increased frequency and magnitude of extreme weather events (Mirza, 2003). The change in the atmospheric composition of gases is attributed to anthropogenic emissions of green house gases such as $CO_2$, $CH_4$, $N_2O$ and other gases.

Effect of climate change encompasses all vital system supporting world populations. Human health, agriculture, forest, water resources and biodiversity will suffer at different scales depending on local conditions. The consequences of climate change can be seen all over the world. The average temperature of the earth's surface has risen by 0.74 ºC since the late 1800s and if the increase in temperature exceeds by 1.5 ºC to 2.5 ºC, there will be the risk of extinction of plant and animal species by 20-30% (IPCC, 2007). By 2020, up to 250 million people in Africa could be exposed to greater risk of water stress (UNFCCC, 2007). There has been an unprecedented warming trend during the $20^{th}$ century. The current average global surface temperature of 15 ºC is nearly 0.6 ºC higher than it was 100 years ago-most of the increase has been the consequence of human activity (IPCC, 2001). A further increase of 1.5-6 ºC is projected for the period to 2100 (IPCC, 2007). Further, the number of natural disasters has increased more and more. Tsunamis, floods and extreme drought have occurred more frequently than in past times. Thus, climate change is a burning issue at present.

### 2.5.1 Climate change in Nepal

The observed data of climate of Nepal indicates the consistent warming and rise in maximum temperature at an annual rate of 0.04 – 0.06º C (MoE, 2010). Although Nepal is responsible for only about 0.025% of total annual greenhouse gas emissions of the world (Karki, 2007), it is experiencing the increasing trends and the associated effects of climate warming. It is particularly vulnerable to climate change due to its fragile mountain ecosystem, where high mountains are warming faster (0.08 ºC per year) than lower hills and the plains (0.04 ºC per year) (Khadka *et al.*, 2013). Nepal's major natural resources, biodiversity and water are at the forefront of climate vulnerability. Further, Nepal has already faced the consequences of climate change such as increase in dry period, intense rainfall, flood, landslides, forest fires, glacial retreats and GLOF threats (Malla, 2008).

The annual mean precipitation is around 1800 mm in Nepal but because of greatly diverse topography it ranges from more than 5000 mm in the south to less than 250 mm in the north. Because of climate change and the rising temperatures, Nepal could face drier phases during dry seasons with wetter monsoon (as much as three times the current level of rainfall) with chances of flooding and landslides during rainy seasons with subsequent impacts on agriculture and livelihoods (Alan and Regmi, 2005). Negative impacts of climate change have been observed in Nepal. It has been reported that 2006 was the warmest year among the twelve warmest years since 1975 to 2007 (Malla, 2008). Traditional rainfalls of Jestha and Ashar (mid July) have been shifted in Shrawan and Bhadra in Nepal and it has affected negatively in the rice production, prime staple food crop of Nepal (Malla, 2008).

Developing countries like Nepal are more susceptible to the climate change and its impacts due to their limited capacity to cope with hazards associated with the changes in climate (Kates, 2000). Nepal has good reasons to be concerned about climate change, where over two million Nepalese people depend on climate sensitive sectors like agriculture and forestry for their livelihood (Garg *et al.*, 2007).

### 2.5.2 Impact of climate change in agriculture

Agricultural productivity is greatly dependent on climate. Being open to vagaries of nature, agriculture sector is highly vulnerable to climate change phenomena. It has been stated that as much as 80% of the variability of agricultural production is due to the variability in weather conditions, especially for rainfed production systems (Fageria, 1992). The critical climatic variables associated with agricultural production are precipitation, air temperature and solar radiation. Rainfall and temperature primarily determine the cropping patterns and the types of crops that may be grown in a particular location. Solar radiation, both solar intensity and duration, has significant effect on crop photosynthesis and reproduction (Amgain, 2004). The physiological processes including alleviation of photosynthetic efficiency, oxidative damage, uptake of water and nutrients by crop are severely affected under continuously changing temperature and moisture disparity (Wang *et al.*, 2011). Similarly, climate change in the form of temperature rise and rainfall variability in many parts of world caused countries cereal grain yield stagnation and increased yield variability (Olesen *et al.*, 2011). Even a temperature rise of 1– 2.5°C will have serious effects, including reduced crop yields, spread of climate sensitive diseases such as malaria, an increased risk of extinction of plant and animal species, water stress, and increased risk of floods as glaciers retreat followed by drought and water scarcity (UN, 2008). Stresses (water & temperature) due to climate change reduce crop growth by affecting various physiological and biochemical processes such as photosynthesis, respiration, translocation and nutrient metabolism (Jaleel *et al.*, 2009; Farooq *et al.*, 2011). Hence, plant growth and productivity is severely affected by nature in the form of biotic and abiotic stresses.

#### 2.5.2.1 Temperature

Air temperature is the main weather variable that regulates the rate of vegetative and reproductive development. In most cases, an increase in temperature causes an increase in the developmental rates. At extremely high temperatures, the inverse result occurs, and developmental rates slow down as the temperature further increases.

Temperature of atmosphere is continuously rising and predicted to rise by 1.8 °C - 4.0 °C by 2100 (IPCC, 2007). High temperature is one of the major environmental factors limiting crop growth and yield (Peng *et al.*, 2004; Sheehy *et al.*, 2005). Increasing temperature will likely directly impact crops by affecting their physiology; it will also indirectly affect crops through changes in the water regime and the increased intensity of pests and diseases (Bale and Maters, 2002).

Increased temperature reduces maturation time (Basak, 2010), resulting in seed sterility and a linear decrease in yield, while biomass remains mostly unaffected (Baker *et al.*, 1990c). Further, a shortening of the development process can also result in incomplete grain filling and reductions in yield (Bachelet *et al.*, 1993). Agronomic studies in India, for instance, suggest that a temperature rise of 4°C would cause a fall in grain yields by 25-40 per cent (Rosenzweig and Parry, 1994). The responses of crop yields to a unit increment in mean temperature of growing season vary from -6 to 16 %, -4 to 11 % and -12 to 3% for three cereals, rice, maize and wheat, respectively, depending on the location and elevation in the Koshi basin of Nepal (Bhatta *et al.*, 2014).

In rice, each of the growth phases is likely to be influenced by increase in temperature. High temperature during and right before the flowering phase may lead to complete sterility (Farrell *et al.*, 2006), while high temperature during vegetative and ripening phases alters the grain filling and thus, the grain quality of the rice (Shrivastava *et al.*, 2012). Further, temperatures higher than 34 °C at the time of flowering may induce sterility, even in temperate regions (Kim *et al.*, 1996). Increase in maximum temperature during ripening phase increases yield, but at a decreasing rate (Welch *et al.*, 2010; Karn, 2014). With 1 °C rise in day-time maximum temperature during the ripening phase of rice increases harvest by 27 kg $ha^{-1}$, but the productivity declines when the daytime maximum temperature goes beyond 29.9°C (Karn, 2014). Since the average maximum temperature is already higher than this threshold, rice yield will likely diminish with any further increases in maximum temperature. Further, the drop in yields of non-irrigated rice will be significant if the temperature increase exceeds 2.5°C (Lal, 2007).

Increase in maximum or minimum temperature has also significant influence in crop performances. Increase in minimum temperature causes reduction in grain yield (Shah *et al.*, 2011) because it increases respiration losses during vegetative stage (Mohammed and Tarpley, 2009b) and hastens crop maturity during ripening stage (Mohammed and Tarpley, 2009a). Minimum temperature above 25°C during the vegetative stage can lead to significant damage to rice yield by reducing plant height, tiller number, and total dry weight (Yoshida *et al.*, 1981). Further, higher maximum temperature also has negative impacts on rice yield during the vegetative and ripening stages (Lobell and Field, 2007; Wassmann *et al.*, 2009).

For rice crop, night time temperature is more important than day time temperature on growth and increasing night time temperatures may reduce yield in tropical regions (Peng *et al.*, 2004; Wassmann and Dobermann, 2007; Welch *et al.*, 2010). Hotter night temperatures can cause increased spikelet sterility in rice and reduce grain yield (Wassmann and Dobermann, 2007). Every 1°C increase in the mean night-time temperature, rice yield declines by 10% during the dry season (Peng *et al.*, 2004).

**2.5.2.2 Solar radiation**

Solar radiation provides the energy for the processes that derive photosynthesis, affecting carbohydrate partitioning and biomass growth of the individual plant components (Boote and Loomis, 1991). Photosynthesis is normally represented through an asymptotic response function, with a linear response at low light intensity (Amgain, 2004). Photosynthetically active radiation (PAR), having the wave lengths of 370-800 nanometers, is most important for the photosynthesis in crop plants. The development of crop plant is mainly governed by day length, an important component of solar radiation.

Solar radiation has positive impact in flower opening of rice. Higher is the solar radiation in early hours of the day, earlier is the opening of flower, thus reducing the risk of sterility because it may lead to anthesis before the air temperature reaches critical level (Kobayasi, 2012). However, higher solar radiation causes the increase in temperatures of leaf and panicles, which results in increased transpiration through leaves and higher water demand of crop. Further, it was revealed that increased solar radiation during vegetative stages has negative impact on rice yield (Welch *et al.*, 2010) and positive during the ripening stage (Welch *et al.*, 2010; Deng *et al.*, 2015). Increased solar radiation with increased temperature, however, would decrease the rice yield (Kawasaki and Herath, 2011).

**2.5.2.3 Carbon Dioxide ($CO_2$)**

Industrial and agricultural emissions of $CO_2$, mainly from the burning of fossil fuels, have resulted in an increase of this gas in the earth's atmosphere. It has been projected that ambient levels of $CO_2$ and temperature will rise significantly. The rise in annual mean concentration of atmospheric $CO_2$ has been documented continuously since 1958. The concentration of atmospheric $CO_2$ was 396.48 parts per million (ppm) in the year 2013, which increased by 0.52% in 2014 and reached 398.55 ppm (NOAA-ESRL, 2015). The atmospheric concentration of carbon dioxide has increased by 31% since 1750 (IPCC, 2001). For the past decade (2005-2014) the average annual increase is 2.1 ppm per year whereas the average for the prior decade (1995-2004) was 1.9 ppm per year (NOAA-ESRL, 2015). During the 1990s the year to year increase varied from 0.9 ppm (0.2%) to 2.8 ppm (0.8%) (IPCC, 2001). Further, the level of $CO_2$ is likely to rise by 2 ppm per year, and thus $CO_2$ levels will reach double the current level by the end of the next century. The prediction on concentration of atmospheric $CO_2$ has shown the increase in $CO_2$ concentration to 540 to 970 ppm by IPCC (2001) and to 882.87 ppm by CI (2013) by the year 2100. The increase in $CO_2$ and other 'green house gases' is likely to induce surface air temperature rises and concurrent changes in precipitation patterns (Bachelet *et al.* 1993).

Several studies show that increases in atmospheric carbon dioxide can significantly stimulate growth, development and reproduction in wide variety of $C_3$ plants including rice (Sage, 1995; Mandersheid and Weigel, 1997; Poorter and Navas, 2003). Increase in $CO_2$ concentration to double results in increase in rice yield and biomass due to increase in the net assimilation rate (Cure, 1985) and concurrent increase in canopy net photosynthesis and water use efficiency with increase in ambient $CO_2$ (Baker *et al.*, 1990a). Further, there will be decrease in leaf conductance and transpiration due to $CO_2$ enhancement. Further, the elevated $CO_2$ accelerates the rice development and shortens the total growth duration (Baker *et al.*, 1990b).

However, increase in $CO_2$ also causes increase in atmospheric temperature. Increase in crop yield due to increase in $CO_2$ concentration will be masked by increase in temperature leading to shortened crop duration in rice, wheat and sorghum (Lal *et al.* 1998). The increased level of $CO_2$ from 340 to 680 ppm could increase the yield of major crops by 10-15 per cent especially in $C_3$ plants like rice (Allen, 1990) but the beneficial effects can be negated as the incidence of a Photosynthetically Active Radiation (PAR) is likely to decline by 1 per cent (Hume & Cattle 1990). Under a double $CO_2$ scenario predicted for 2100, rice yield in Nepal is expected to drop by about 4.2 per cent relative to current production levels (Karn, 2014).

**2.5.2.4 Rainfall**

Precipitation acts as a modifier and indirectly affects many of plant growth and developmental processes. Low precipitation leads to drought stress, which reduce gross carbon assimilation through stomatal closure, causing a modification of biomass partitioning to the different plant components. Water logging stress can cause lack of oxygen in the rooting zone required for root growth and respiration and results in decrease in root activities, causing root senescence and increased root death rates. Further, water logged condition results in reduced water uptake.

Heavy rainfall during the nursery phase has a negative and significant effect on rice yield (Karn, 2014). If rain increases in the vegetative phase, then it is likely to affect the crop growth and biomass yield positively (Bakul *et al.*, 2009), but rainfall during reproductive stage has negative impact on rice yield (Chen *et al.*, 2015).

Climate change has also altered the monsoon pattern all over the world. Several research indicates that the monsoon has changed in two significant ways during the past half century: it has weakened (less total rainfall during June-September) (Ramanathan *et al.*, 2005; Dash *et al.*, 2007; Ramesh and Goswami, 2007); and the distribution of rainfall within the monsoon season has become more extreme (Goswami *et al.*, 2006; Dash *et al.*, 2009).

Changing of rainfall pattern affects the rice crop at different times. The growth duration of rice plant is significantly affected by the variability of rainfall during early period and it is also mentioned that the variability of rainfall is associated with an untimely cessation at the reproductive or ripening stage of the rice crop, yield reduction is severe (Basak, 2012). The yield of rice in Thailand is expected to decline about 18% in the 2020s because of alternations in temperature and rainfall cycle and through changes in soil quality, pests and diseases as the impacts of climate change (Agarwal, 2008).

### 2.5.3 Impact of climate change in Nepalese agriculture

Nepalese agriculture has also been affected by climate change. Climate-related changes have been observed in precipitation patterns, temperature, high intensity floods, landslides, erosion and increased sedimentation (Shrestha, 2004; Karn, 2007). Climate change has increased variability of rainfall, increased temperature, increased drought frequency and period, changes in monsoon time, reduction of annual rainfall, decreased rainfall frequency and duration per event, decreased winter rainfall, and increased frequency of erratic rainfall in Nepal (Tiwari and Bauer, 2015).

Limited water availability, decreasing soil moisture, high fluctuation in crop yield, increased incidence of pests and diseases, existence of unidentified pests and increased sand in soils due to flood are some frequent problems encountered in agricultural sector of Nepal (Tiwari and Bauer, 2015). Late or pre-monsoon, unusual precipitation, decreased rainy days and intense rainfall events caused more runoff and low groundwater recharge (Malla, 2008). Delays in the onset of the monsoon has hamper timely rice plantation and has affected yields (Karn, 2014). The frequency and intensity of droughts seem to have increased, particularly during the summer and the normally drier. Because of climate change it is reported untimely start of monsoonal rainfall that resulted rain deficit in the eastern Terai lowlands in 2005/06, reducing crop production by 12.5% nationwide (Malla, 2008). About 10% of agricultural land was left fallow due to rain deficit on the one hand, while on the other hand in the mid- western Terai faced heavy rain with floods, which reduced crop production by 30% (Regmi, 2007). Changes in seasonality i.e. weather patterns becoming less predictable, weather events typical of one season occurring in another, increasing extreme events, changes in the behavior of key crops have meant that traditional and indigenous knowledge on climate and plants relationships have become less reliable (Karn, 2014).

The maximum temperature in Nepal has increased by 1.8°C over the period 1975 to 2006, and precipitation has become more erratic (Baidya *et al.*, 2008). During 1977 and 1994, the Terai region has, on average, seen an increase in annual temperature of 0.04°C per year (Shrestha, 2004). Early maturity of the crops due to increase in temperature has helped to have more crops in the same crop cycle. However, increase in temperature causes decrease in grain filling period due to increase in respiration process, decreased fertilizer use efficiencies; shift in agricultural zone, increase in insect pest population, desertification, increase in soil erosion and soil evapotranspiration (Malla, 2008); which causes reduction in crop yield. Shifting of climatic zones due to climate change has been observed in the country which has resulted in extinction of some indigenous crop varieties such as many aromatic rice varieties including Basmati rice, some local wheat, maize, and other agricultural crops as well (Paudel, 2012). Probable vulnerabilities due to increase in atmospheric temperature are decrease in water table, increase in evapotranspiration, soil erosion, landslides, floods, inundation of standing crops and reduction of soil fertility. This has lead to the decrease in agricultural production and can have a devasting impact on household food security. Thus, some farmers have begun to take adaptation measures such as changing the agricultural calendar, crop diversification, crop rotation, changing cropping patterns, adopting climate smart technologies like drought resistant cultivars and resorting to alternate sources of irrigation like rain water harvesting etc (Karn, 2014; Tiwari and Bauer, 2015).

**2.6 Decision Support System for Agrotechnology Transfer (DSSAT)**

A model, for general purposes, is defined as a mathematical representation of a system and modeling is the process of developing that representation (Maria, 1997). Further, model can be defined as a prototype, a simplified representation, as well as an abstraction of a reality (system) (Dourado-neto *et al.*, 1998). Simulation is the process of developing the model and analyzing system through them. Simulation includes the processes in which a similar artificial and or mathematical system is developed to represent and function as a real system illustration to compute the behavior of a system. Developing computer logic and flow diagrams, writing the computer code, and implementing the code on a computer to produce desired output from analyzing the system are necessary tasks in the simulation process. Conceptually, the process of developing a model of a system is a prerequisite to simulation and not the actual simulation process, but in practice modeling and simulation are closely related and come together in discussion.

A range of technologies has been identified in recent years, which have the potential to increase resource use efficiently, reduce adverse environmental impacts, and increase crop productivity in Asia. It is assumed that evaluation and site-specific adaptation of these technologies can be assisted through crop simulation models. A mathematical model whose solution is obtained by numerical approximation usually involving computers is called simulation model (Datta, 2008). Among several models evolved, the Decision Support System for Agrotechnology Transfer (DSSAT) is pioneer one.

DSSAT was originally developed by an international network of scientists; cooperating in the International Benchmark Sites Network for Agro technology Transfer (IBSNAT) project (Jones *et al.*, 1998; Iyanda *et al.*, 2014; Kaur *et al.*, 2015; Anar *et al.*, 2015). IBSNAT project was a USAID funded project based at University of Hawaii (Jones and *Kiniry,* 1986; Singh *et al.*, 2002). The IBSNAT suites of crop models represent many of the major staple food crops and have been widely calibrated and validated in many countries. DSSAT ver. 4.5 is one crop simulation model which can help to investigate a range of issues from crop management (Jones *et al.*, 2003).

DSSAT is a comprehensive multi-disciplinary model which provides the valid outputs. It is software designed to provide users with easy access to soil, weather, crop and experimental data as well as simulation models to simulate outcomes of alternate management strategies. In an actual sense, DSSAT models help users by reducing the time and human resources frame work to carry out scientific operation through research to integrate and apply new knowledge to the particular research questions (Tsuji, 1998) that are imperative to investigate. Further, DSSAT includes process based, mechanistic and management oriented models that simulate growth and development of various crop grown in temperate and tropical environments in the world (Tsuji et al., 1994). It contains multiple crop models including CERES-Rice and provides a facility for simulating crop sequences. The DSSAT model simulates crop growth, development, and yield taking into account the effects of weather, management, genetics, and soil water, C and N (Timsina and Humphreys, 2006b).

**2.7 CSM-CERES-Rice**

Simulation models of soil-crop systems are tools that can help to understand crop responses (Timsina *et al.*, 2001). Crop simulation models integrate the current state of art and scientific knowledge from many different disciplines, including crop physiology, plant breeding, agronomy, agrometeorology, soil physics, soil chemistry, soil fertility, plant pathology, entomology, economics and many others. These models in general calculate or predict crop growth and yield as a function of genetics, weather conditions, soil conditions and crop management.

CERES model system allows user to screen new technology packages, such as a new cultivar or fertilizer management strategies, without spending excess time on expensive, time consuming field trials. These models can be used to understand the influence of agronomic management and climatic variables on crop growth and yield, when conventional field experiments have limitations because of various confounding factors (Amgain *et al.*, 2006).

The CERES models analyze growth on a daily time step and require daily weather data (maximum and minimum temperature, solar radiation and precipitation). They compute phasic and morphological development of crop using temperature, day length and cultivar characteristics (Jones *et al.*, 1998). Daily dry matter growth is based on light intercepted by leaf area index multiplied by a conversion factor. Biomass partitioning into various plant components is based on potential growth of organs and daily amount of growth produced. Soil water and nitrogen balance sub models provide daily values of supply to demand ratios of water and nitrogen, respectively, which are used to influence growth and development rates (Jones *et al.*, 1998).

The CERES models simulate growth by taking into account the following processes (Jones *et al.*, 1998):

- Phenological development, especially as it is affected by genotype, temperature and daylength. 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 sufficiency severe, 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 filling.

The CERES-Rice model is similar to other CERES models, with several additional features. CSM-CERES-Rice is process based, management-oriented model that can simulate the growth and development of rice as affected by varying levels of weather, water, nitrogen, and cultivar characteristics (Jones *et al.*, 2003). The model processes indicate the effects of elevated $CO_2$ and changed climatic parameters such as increased or decreased temperatures, rainfall and solar radiation (Amgain *et al.*, 2006). These models have been validated and tested across the world, including many countries in Asia (Timsina and Humphreys, 2003) and in N-W India (Timsina *et al.*, 2004), and hence are suitable for investigating the sensitivity of both rice and wheat yields to $CO_2$ and climate change parameters.

In CSM-CERES-Rice, the effect of transplanting on growth and development has been added. Another feature allows the water balance to simulate crop water use under flooded rice systems, under upland conditions, or under intermittent flooding and dry soil surface conditions. Finally, the nitrogen sub model required rather major modifications to simulate Nitrogen transformations under flooded and intermittent flooded and upland conditions (Jones *et al.*, 1998).

**2.8 Opportunities of using CERES model**

Various authors have offered various reasons for building and applying crop models. Whisler *et al.* (1986) summarized reasons in to three broad categories; (i) as aid in interpreting experimental results, (ii) as agronomic research tools, or (iii) as agronomic grower tools, while Boote *et al.* (1996) categorized them in to other three categories: (i) research knowledge synthesis, (ii) crop system decision management and (iii) policy analysis. Mathew and Stephens (2002) further grouped them in to other three categories: (i) as tools in research, (ii) decision support and in (iii) education and training.

Model can be used to assist both tactical decision making (such as irrigation scheduling, and fertilizer and pest management), or in strategic decision making , such as planning for climate change or to avoid salinization, yield forecasting and planning for national food requirements . Model can also be useful in teaching crop and soil processes and crop system behavior in response to weather, management and site conditions (Timsina and Humphreys, 2003).

CSM-CERES-Rice model was used to examine the anthesis and maturity dates in Asia and Australia and prediction on those dates by the model was found fairly well (Timsina and Humphreys, 2006b).

CSM-CERES-Rice model was used to simulate the growth and yield of rice for irrigated semi arid conditions in Pakistan and found that the model was able to simulate accurately (Ahmad *et al.*, 2013). Similarly, the model was also used to predict the growth, development and response to various climatic conditions in Kenya under prevailing in the different irrigation schemes (Nyang'au *et al.*, 2014).

CSM-CERES-Rice model was used to simulate the water saving irrigation and conservation agriculture practices in Uzbekistan. Further, the models were used to explore the long-term impact of water saving irrigation and conservation agriculture practices on grain yield, soil organic carbon dynamics, N dynamics, and water balance in a rice–wheat rotation for 39 years starting from 1971. The simulation results showed that the simulated yield of water-seeded rice without residue retention and flood irrigation is likely to remain the highest and constant over 39 years (Devkota *et al.*, 2015). Similarly, the model was used to simulate the rice yield under different levels of irrigation in Tarahara, Nepal and was found that 3 mm irrigation rate was most effective for higher yield (Rai *et al.*, 2011).

CERES-Rice has also been used to investigate optimum transplanting date of rice for several locations in Asia. The optimum rice transplanting date for Pantanagar, India was suggested from mid July (Timsina *et al.*, 1995). Similarly, the mid July was also found to be the most effective transplanting date in Tarahara, Nepal (Rai *et al.*, 2011).

CERES-Rice has also been used to study the impact of climate change on phenology, growth and yield (Amgain *et al.*, 2006; Rai *et al.*, 2011; Oteng-Darko *et al.*, 2012; Nyang'au *et al.*, 2014).

**2.9 CSM-CERES-Rice model in effect of climate change**

Crop growth and yield under optimal conditions are largely determined by weather during a growing season. The variability of climate, and especially the associated weather extremes, is currently one of the concerns of the scientific as well as the general community. Crop simulation models have been used around the world to assess the impacts of global climate change on yield and water use requirement and to identify potential adaptation strategies (Rosenzweig and Iglesias, 1998).

CERES-Rice has been used to study the impact of climate change on phenology, growth and yield (Amgain *et al.*, 2006; Rai *et al.*, 2011; Oteng-Darko *et al.*, 2012; Nyang'au *et al.*, 2014). In most of the studies, increase in temperature by 2-4°C reduced the growth duration and yield. Increments in both maximum and minimum temperature by any degree celsius decreased the rice yield in Tarahara, Nepal (Rai *et al.*, 2011). Increments in both maximum and minimum temperatures by 4°C decreased the rice yield by 34% in India (Amgain *et al.*, 2006) and in Ghana (Oteng-Darko *et al.*, 2012). Increase in both maximum and minimum temperature by 4°C decreased the growth duration by 11 days in Ghana, while decrease in both maximum and minimum temperature by 4°C increased the growth duration by 21 days (Oteng-Darko *et al.*, 2012).

By increasing both maximum and minimum temperature along with increase in $CO_2$ concentration, rice yield was decreased in Tarahara, Nepal (Rai *et al.*, 2011). By increasing 4°C for both maximum and minimum temperature along with an increase in $CO_2$ concentration by 20 ppm from the standard $CO_2$ concentration of 335 ppm (in India) and 330 ppm (in Ghana), the reduction in rice yield was 33% in India (Amgain *et al.*, 2006) and in Ghana (Oteng-Darko *et al.*, 2012). Similar change in temperatures along with increases in solar radiation by 1 $MJm^{-2}day^{-1}$, the reduction in rice yield was 32% in India (Amgain *et al.*, 2006) and in Ghana (Oteng-Darko *et al.*, 2012). Further, decrease in both maximum and minimum temperature by 4°C along with increases in solar radiation by 1 $MJm^{-2}day^{-1}$, there was increase in the rice yield by 33% and growth by 22 days in Ghana, showing the interactive effect of temperature and solar radiation (Oteng-Darko *et al.*, 2012).

Climate change could increase or decrease rainfall in conjunction with increases or decrease in solar radiation and temperature. Doubling of the green house gasses would increase minimum and maximum temperature and increase the solar radiation by 1.2-2.1% and rainfall by 20.5-91.7% in Indonesia (Amien *et al.*, 1999). In rainfed areas of India and Indonesia both, any decrease in rainfall due to climate change would decrease rainfed rice yields, while increased rainfall would increase yields (Amien *et al.*, 1999; Saseendran *et al.*, 2000).

**2.10 Determination of genetic coefficient**

Genetic coefficients are sets of parameters that describe the genotype and environmental interactions (IBSNAT, 1993). They summarize quantitatively how a particular cultivar responds to environmental factors. Genetic coefficients can be determined in controlled or field conditions (Nyang'au *et al.*, 2014). However, plant growth in controlled environment chambers often differs markedly from growth in the field. Since most model users do not have controlled environmental facilities, most determinations will use field data (Acock and Acock, 1991; Hunt and Pararajaingham, 1994).

The genetic coefficients that influence the occurrence of developmental stages in the CERES models can be derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed number of days to the phenological events. To evaluate datasets, default genetic coefficients for RR21, a widely grown wheat cultivar in south Asia, available in an earlier version of the DSSAT shell, and a close ecotype to which the cultivar would belong, were used to derive the cultivar coefficients for HD 2285 and HD 2329 used in the study by Timsina and Humphreys (2006a).

### *2.11* Model calibration

After model development, its parameters are determined through field experiments or literature search. Adaptation of model parameters to an experimental situation is called model calibration. In other words, adjustment of parameters so that simulated values compare well with observed values is called model calibration (Tsuji *et al.*, 1994). Further, it is also known as parameterization. Calibration is done by increasing or decreasing values of model parameters (Hofmann, 2005). This should be done with caution because it decreases the explanatory nature of model. Agronomist and plant breeders uses genotype coefficient for changing so that the model becomes calibrated.

### 2.12 Model validation

After parameterization, model behavior is compared with the real experimental situation. This process is known as model validation. In other words, to test the model whether it is fit or unfit to a given environmental condition is called model validation. Further, it is also known as scenario analysis.

The correlation coefficient and the coefficient of determination are of little practical value in evaluating the predictive capabilities of models because their magnitudes are not consistently related to the accuracy of the prediction (Willmott, 1982). More appropriate criteria include mean bias error (MBE), root mean square error (RMSE) and mean absolute percentage error (MAPE). These measures are defined as follows:

$$\text{MAPE} = \frac{1}{n}\left[\sum_{i=1}^{n}\left(\left|\frac{data_i - model_i}{data_i}\right|\right)100\right]$$

$$\text{RMSE} = \left[\frac{\sum_{i=1}^{n}(model_i - data_i)^2}{n}\right]^{0.5}$$

$$\text{MBE} = \frac{1}{n}\left[\sum_{i=1}^{n}(model_i - data_i)\right]$$

Where model i is the i^th^ forecast value, data i is the i^th^ mean measured value and n is the number of observations.

The RMSE was used to estimate the variation, expressed in the same unit as the data, between simulated and measured values (Xevi et al., 1996). The RMSE tests the accuracy of the model, which is defined as the extent to which simulated values approach a corresponding set of measured values (Loague and Green, 1991). The coefficient of residual mass (CRM) was used to measure the tendency of the model to overestimate or underestimate the measured values. A negative CRM indicates a tendency of the model toward overestimation (Xevi et al., 1996). The CRM is defined by

$$\text{CRM} = \frac{\sum_{i=1}^{n} M_i - \sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} M_i} \times 100$$

Where, $M_i$ and $S_i$ are the measured and simulated values, respectively, for the $i^{th}$ data point of n observations.

Use of RMSE and D-index for the validation of model has been suggested by Willmott et al. (1985).

$$\text{D-index} = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i'| - |O_i'|)^2}\right]$$

Where, n is total number of observations, $P_i$ is the predicted value for the $i^{th}$ measurements, $O_i$ is the observed value for the $i^{th}$ measurement, and $P_i' = P_i - \ddot{O}$ and $O_i' = O_i - \ddot{O}$, where Ö is overall mean of the observed values.

**2.13 Sensitivity analysis of model**

Sensitivity analysis is a procedure of determining changes in model output with an increase or decrease in value of a parameter or combination of parameters. In other words, sensitivity analysis is answering to “what if” and “how much” questions. Further, it is also known as model refinement process. The purpose of sensitivity analysis is to study the behavior of model (Jones and Luyten, 1997). If the change in the output is large, then model is considered sensitive to that parameter. Sensitivity analysis is valuable in assessing several useful theoretical applications including yield gap analysis, strategic decision making planning and climate change studies (Timsina and Humphreys, 2003). DSSAT has a facility to automatically do sensitivity analysis for selected variables.

# 3 MATERIALS AND METHODS

The study comprises two activities: the first was field experiment at farmers' field at Nawalparasi, and the second was about the CSM-CERES-Rice for simulation modeling.

## 3.1 Field experimentation

All the detail about the experimental materials and methods used during the entire period of experimentation has been described under the following heading given below.

### 3.1.1 Location and cropping history

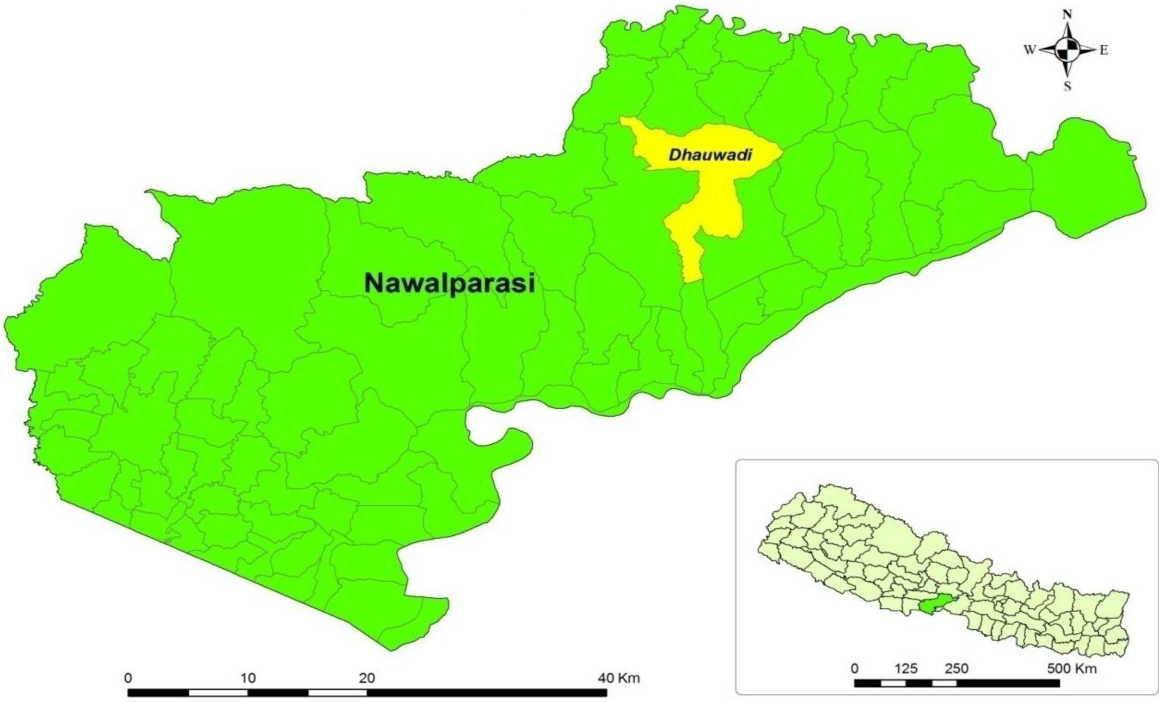


Figure 1. Map of experimental site (Dhauwadi VDC, Nawalparasi)

The field experiment was conducted at Dhauwadi VDC of Nawalparasi district (235 masl) in farmers' field (27° 48' 43" N latitude and 84° 4' 58" E longitude) from June to October, 2014. The site is situated in central Nepal 7 km north from Danda, a local market in East-West highway; and about 76 km North-East from Parasi, Headquarter of

Nawalparasi. Maize crop was cultivated in the experimental field before rice planting and rice-potato-maize was the cropping system of the site.

### 3.1.2 Climatic condition during experimental period

The experimental site lies in the sub-tropical humid climate belt of Nepal. The area has sub-humid type of weather condition with cool winter, hot summer and distinct rainy season. It is characterized by three distinct seasons: rainy season (June to October), cool winter (November to February) and hot spring (March to May). January was the coldest month and June was the hottest month. The minimum temperature (7-13.3 °C) never goes to freezing point even during the coldest month, whereas the maximum temperature recorded during the hottest month was 45.8°C. However, the average minimum and maximum temperature during the coldest and the hottest month was 10.25°C and 43.60°C, respectively.

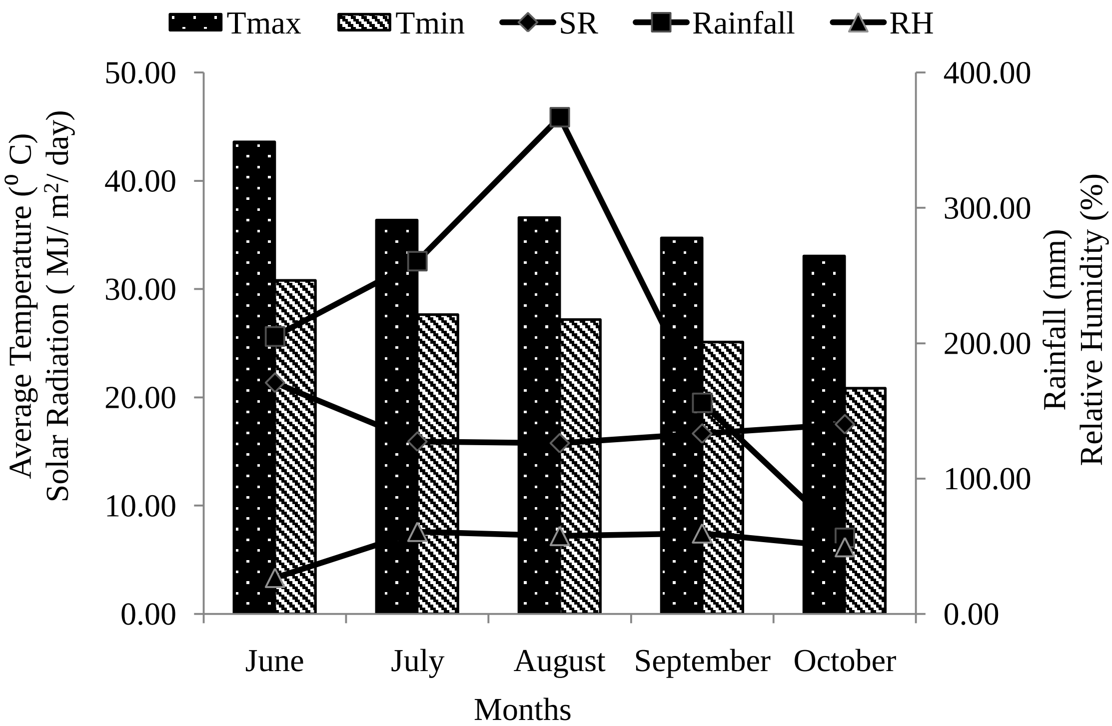


Figure 2. Weather data of experimental site for crop growing period at Dhauwadi, Nawalparasi, Nepal during 2014

The experimental site received the total rainfall of 1215 mm during the entire period of the experimental year 2014, whereas 1045 mm of rainfall was recorded in the rice growing period (June to October). Humidity started rising up from April (average 17.92%), reached 60.66% in July and again started declining.

### 3.1.3 Soil analysis

Soil samples from field were taken before transplanting of the seedlings from each replication and analyzed for their routine analysis. The soil samples were taken by core sampler from various soil profiles up to about 1 m depth of the soil layer. Soil samples were analyzed at Agricultural Technology Centre, Pulchowk, Lalitpur.

#### 3.1.3.1 Mechanical analysis

The collected samples were analyzed for soil texture by hydrometer method. The soil of experimental site was loam in texture. The percentage of sand was increased with increasing depth except the depth 0-20 cm whereas the silt percentage was decreased with increasing depth except the depth at 20-40 cm. Further, clay percentage was more or less equal in all depths except the depth 0-20 cm (Table 1).

Table 1. Mechanical properties of soil of experimental site during 2014 at Dhauwadi VDC, Nawalparasi

| Soil depth | Sand (%) | Silt (%) | Clay (%) | Texture |
|---|---|---|---|---|
| 0-20 cm | 39.67 | 47.87 | 12.47 | Loam |
| 20-40 cm | 33.67 | 48.87 | 17.47 | Loam |
| 40-60 cm | 37.67 | 46.70 | 15.63 | Loam |
| 60-80 cm | 37.00 | 45.87 | 17.13 | Loam |
| 80-100 cm | 41.00 | 43.87 | 15.13 | Loam |

#### 3.1.3.2 Physical analysis

The physical properties of the soil especially soil moisture gradient and bulk density at various profiles were determined. The results are presented in Table 2. Drained upper limit (DUL) and drained lower limit (DLL) values were automatically calculated by using CSM-CERES-Rice (DSSAT Ver. 4.5) model. DUL and DLL were known as the highest and the lowest field measured water content of soil after it had been thoroughly wetted and allowed to drain until drainage became practically negligible, respectively.

The DUL, DLL and moisture measured at saturation was found to be constant for various depths whereas soil compactness was found to be the highest at 0-20 cm depth along with the highest bulk density.

Table 2. Physical properties of soil of experimental site during 2014 at Dhauwadi VDC, Nawalparasi

| Soil depth | Drained upper limit (DUL) (bars) | Drained lower limit (DLL) (bars) | Soil moisture content at saturation (bar) | Bulk density (Db)(g $cm^{-3}$) |
|---|---|---|---|---|
| 0-20 cm | 0.295 | 0.126 | 0.357 | 1.62 |
| 20-40 cm | 0.300 | 0.138 | 0.383 | 1.56 |
| 40-60 cm | 0.276 | 0.124 | 0.417 | 1.47 |
| 60-80 cm | 0.280 | 0.130 | 0.399 | 1.52 |
| 80-100 cm | 0.263 | 0.119 | 0.378 | 1.58 |

**3.1.3.3 Chemical analysis**

Soil $p^H$ was analyzed by 1:1 soil water method and found to be slightly acidic in nature at the experimental site. As the depth of soil profile goes increasing, the $p^H$ was in decreasing trend. Total nitrogen was analyzed by Kjeldahl distillation unit. It was found medium in upper soil depth (0-20 cm), but found to be lower in amount with increasing depth. Available phosphorous was analyzed by Modified Olsen’s Bicarbonate method. High amount of available phosphorus was recorded in upper soil depth (0-20 cm), where as in the remaining soil depths, it was in medium amount. Soil available potassium was evaluated by Flame Photometer and found higher amount in upper soil depth (0-20 cm) where as in the remaining soil depths, it was found to be medium amount. The % organic carbon was determined by Walkly and Black method and found low in all soil depths.

Table 3. Chemical properties of soil of experimental site during 2014 at Dhauwadi VDC, Nawalparasi

| Soil depth | Soil $p^H$ | $NH_4^+$ N (%) | $NO_3^-$ N (%) | Total N (%) | $P_2O_5$ (Kg $ha^{-1}$) | $K_2O$ (Kg $ha^{-1}$) | Organic Carbon (%) |
|---|---|---|---|---|---|---|---|
| 0-20 cm | 5.53 | 0.0097 | 0.0167 | 0.12 | 100.86 | 285.87 | 1.38 |
| 20-40 cm | 4.92 | 0.0063 | 0.0103 | 0.08 | 43.05 | 254.60 | 0.90 |
| 40-60 cm | 4.78 | 0.0053 | 0.0097 | 0.06 | 35.53 | 245.60 | 0.73 |
| 60-80 cm | 4.73 | 0.0053 | 0.0097 | 0.06 | 52.90 | 245.60 | 0.67 |
| 80-100 cm | 4.70 | 0.0050 | 0.0097 | 0.06 | 37.67 | 232.27 | 0.65 |

### 3.2 Experimental details

#### 3.2.1 Field layout

The experiment was carried out in strip plot design in the field of three farmers' field and each farmer was considered one replication. The treatment consists of combination of the column factor (three rice management practices: SRI, ICM and Conventional) and row factor (four rice cultivars Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2). The size of each plot was 12 $m^2$. The space between two plots was 0.5 m and 0.5 m between each management practices. The bund of 0.5 m was made between each management practices to check the flow of water and nutrients between them. The crop geometry was different for different management practices as 25 cm × 25 cm in SRI, 20 cm × 20 cm in ICM and 20 cm × 15 cm in conventional practices. The number of seedling was also different as 1, 2 and 3 in SRI, ICM and conventional practices, respectively. Four rows in SRI and six rows in ICM and conventional practices were taken as the net plot after leaving one border row in each side, one destructive sampling row and one guard row.

### 3.2.2 Treatment detail

**Factor A (Column factor):** Rice management practices

- $C_1$: SRI
- $C_2$: ICM
- $C_3$: Conventional

**Factor B (row factor):** Cultivars

- $V_1$: Sukkha-3
- $V_2$: Sukkha-4
- $V_3$: Sukkha-5
- $V_4$: Hardinath-2 (check)

**Treatment combination**

$T_1 = C_1V_1$ = SRI + Sukkha-3

$T_2 = C_1V_2$ = SRI + Sukkha-4

$T_3 = C_1V_3$ = SRI + Sukkha-5

$T_4 = C_1V_4$ = SRI + Hardinath-2

$T_5 = C_2V_1$ = ICM + Sukkha-3

$T_6 = C_2V_2$ = ICM + Sukkha-4

$T_7 = C_2V_3$ = ICM + Sukkha-5

$T_8 = C_2V_4$ = ICM + Hardinath-2

$T_9 = C_3V_1$ = Conventional + Sukkha-3

$T_{10} = C_3V_2$ = Conventional + Sukkha-4

$T_{11} = C_3V_3$ = Conventional + Sukkha-5

$T_{12} = C_3V_4$ = Conventional + Hardinath-2

**Field layout:**

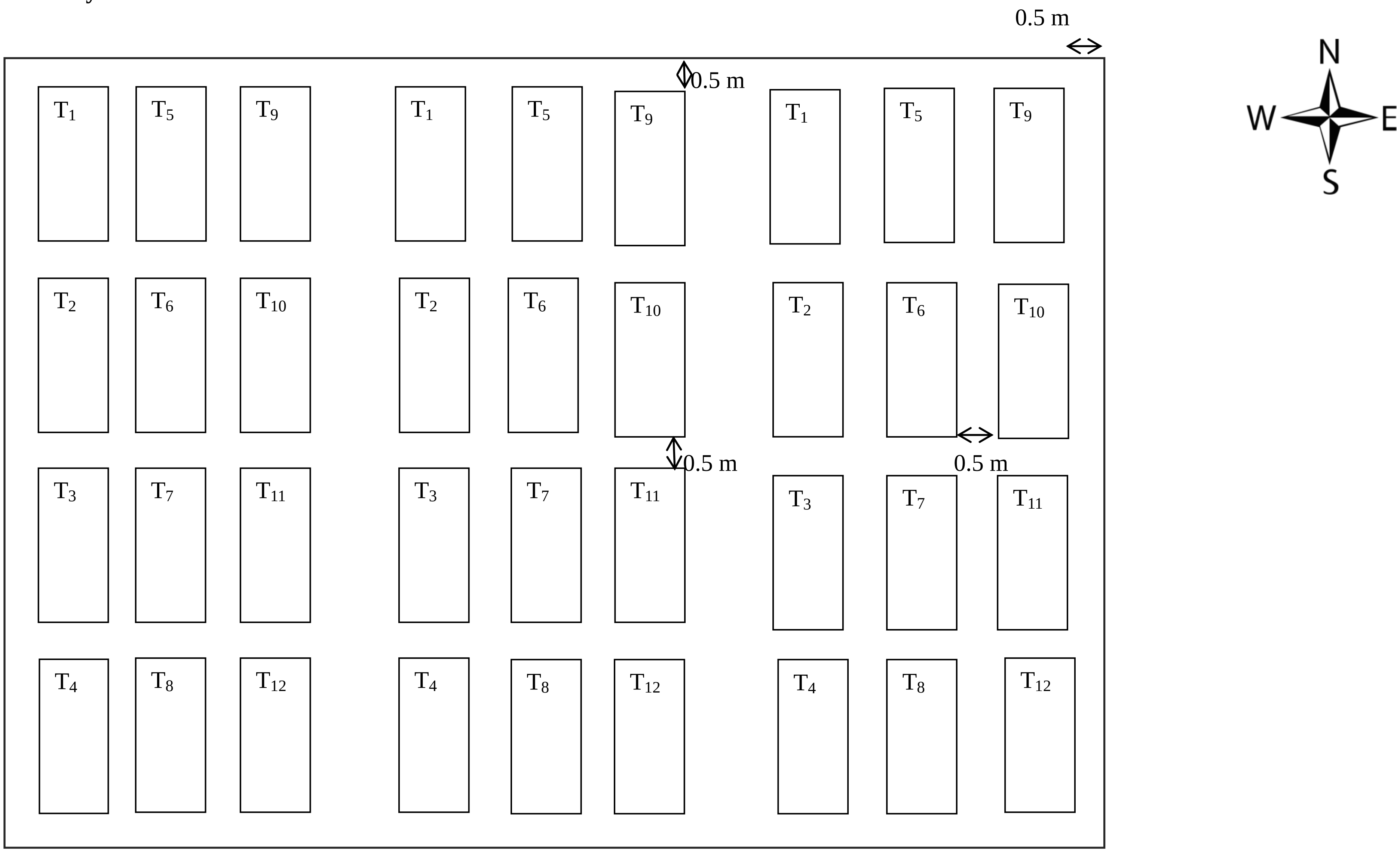


Figure 3. Layout of experimental plot

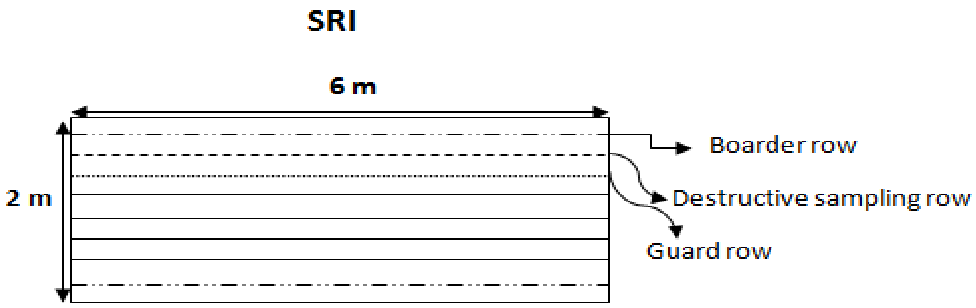


Figure 4. Layout of individual plot under SRI management practice

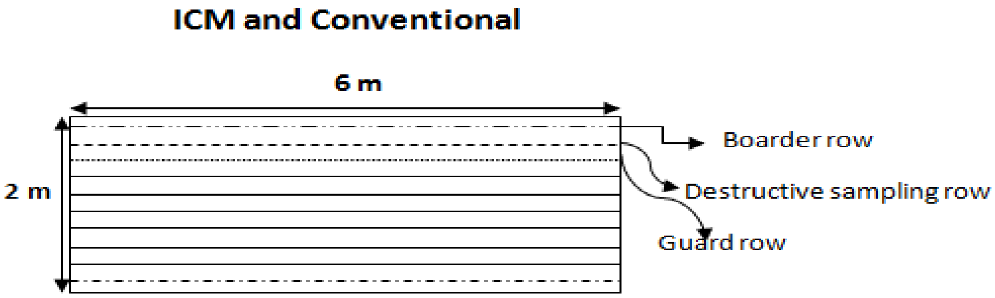


Figure 5. Layout of individual plot under ICM and Conventional Management practices

**3.3 Characteristics of tested cultivars**

Table 4. Characteristics of tested cultivars of rice at Dhauwadi VDC, Nawalparasi, 2014

| Cultivars | Parents | Year of Release | Origin | PM (days) | Yield potential (t $ha^{-1}$) | Test wt (g) | Recommended domain |
|---|---|---|---|---|---|---|---|
| Sukkah-3 | IR55419-4-2/ Wayrarem | 2011 | IRRI | 122-125 | 3.2-4.2 | 23 | Terai, inner terai, river basins |
| Sukkah-4 | IR77298-14-1-2-10 / IR77298 -5-6-195 | 2014 | IRRI | 125 | 3.7-4.5 | 19-20 | Terai, inner terai, river basins |
| Sukkah-5 | IR72022-46-2-3-3-2/ Swarna | 2014 | IRRI | 125 | 3.2-4.2 | 20-21 | Terai, inner terai, river basins |
| Hardinath-2 | IRAT112/ IR50 | 2010 | Indonesia | 125 | 3.1-4.2 | 20 | Terai and inner terai |

(Sources: NARC, 2014; Chaudhary, 2015)

### 3.4 Cultural operation

### 3.4.1 Raising seedlings

As per the requirement of treatments, twelve nursery beds of 1.5 m length and 1 m breadth were prepared for each management practices and varieties. Bold and healthy seeds of all varieties were selected for the sowing. Seeds were sown on 21$^{st}$, 14$^{th}$ and 7$^{th}$ of June 2014 with the seed rate of 7.5 kg ha$^{-1}$, 20 kg ha$^{-1}$ and 40 kg ha$^{-1}$ for SRI, ICM and conventional management practices, respectively. Well decomposed FYM was thoroughly mixed with pulverized soil and there was no use of chemical fertilizers while preparing nursery beds.

### 3.4.2 Land preparation

The experimental plot was prepared by criss-cross ploughing twice a day before transplanting. This was done because the previous crop (maize) was not harvested till that date. The bunds were made between the management practices before ploughing. The experimental plot was divided into 12 plots in each farmer's field. There after ploughing was done by bullock drawn local plough followed by puddling.

### 3.4.3 Fertilizer application

Organic manure @ 10 t ha$^{-1}$and 5 t ha$^{-1}$ were applied in SRI and ICM management practices before last ploughing and incorporated in the soil, whereas, 100% NPK was added in conventional management practices. Vermicompost was used as a source of organic manure. N, $P_2O_5$ and $K_2O$ were applied @ 20:15:10 kg ha$^{-1}$, 40:30:20 kg ha$^{-1}$ and 80:60:40 kg ha$^{-1}$ in SRI, ICM and conventional management practices, respectively. Urea, DAP and MOP were used as sources of N, $P_2O_5$ and $K_2O$, respectively. Full doses of phosphorus and potassium and half dose of nitrogen were applied as basal dose at the time of transplanting. The remaining half dose of nitrogen was applied in two split doses ( $\frac{1}{4}$ N at the stage after 30 DAT, which was close to panicle initiation and remaining $\frac{1}{4}$ at booting stage).

### 3.4.4 Transplanting / Gap filling

The 14 days, 21 days and 28 days old seedlings under SRI, ICM and conventional management practices were transplanted on 4$^{th}$ of July 2014 in the plots with 1, 2 and 3 seedlings per hill at 25 cm × 25 cm, 20 cm × 20 cm and 20 cm × 15 cm geometry in SRI, ICM and conventional management practices, respectively. Gap filling was done frequently after transplanting of rice seedlings to maintain the desired plant population in the experimental plots whenever it was needed.

### 3.4.5 Water management

Alternating wetting and drying was maintained in SRI plots. In conventional plots, flooded condition was maintained throughout the cropping period just before hard dough stage. However, in ICM plots, intermediate condition was maintained. Irrigation was given whenever necessary in these plots. During puddling, irrigation was applied through motor operated through motor operated pump and water was conveyed from nearby channel.

### 3.4.6 Weed management

Herbicide was not applied to control weed since puddling was followed properly in all management practices. Once hand weeding was done at 30 DAT to reduce the competition between weeds and crop for nutrients, spaces, light and moisture. Second light weeding was done at 45 DAT at SRI plots only.

### 3.4.7 Plant protection measures

Severe infestation of stem borer was seen during earlier stages (25-30 DAT) of crop growth in all experimented plots. Insecticide Rhino 505 (Chloropyriphos 50% + Cypermethin 5% w/w) was sprayed @ 2 ml / liter of water to control stem borer. AX-ZINC (chelated Zinc 12 % w/w) was also sprayed @ 1 g / liter as amendment for zinc deficiency in the experimental plots for all management practices and varieties tested. Further, HYFER (plant hormone Auxin) @ 3 ppm was also sprayed for better growth of crop at same period of plant growth.

**3.4.8 Harvesting and threshing**

The crop from net plot area was harvested manually with the help of sickles. The whole plant was cut at 2 cm above ground for all varieties except Hardinath-2. Hardinath-2 variety was harvested by hand picking of panicles due to heavy rainfall during harvesting period. Harvested plants of remaining varieties were left *in-situ* in the field for 3 days for sun drying. Thereafter, small handy bundles were tied and threshing was done manually. Threshing of Hardinath-2 variety was done manually by rubbing the panicles by hands and legs. The grains were cleaned by winnowing and weighted at their exact moisture content.

**3.5 Biometrical observations**

**3.5.1 Plant height**

Ten plants were used to measure the plant height and the average has been taken and expressed as plant height in centimeter (cm). The measurement of plant height was done at 15 days interval from 30 DAT to harvest. The plant height was measured from base to tip of upper leaves or the tip of panicle, whichever is longer, with the help of measuring tape.

**3.5.2 Tillers number per square meter**

Number of tillers per plant was counted from five hills of the first row of net plot at 15 days interval from 30 DAT up to harvest and this value was used to calculate number of tillers per square meter. The fixed hills were used to count tillers number in each reading.

**3.5.3 Leaf area index**

Leaf area of the functional leaves was taken at 15 days intervals from 30 DAT up to 75 DAT. Leaves were selected from two hills of sampling row of the plot. Destructive sample was used for leaf area measurement. The leaf area was measured by Automated Leaf Area Meter. The leaf area so obtained was then used to calculate the leaf area index.

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Ground area (cm}^2\text{)}}$$

**3.5.4 Above ground dry matter**

The same plants, used for measuring leaf area, were used for expressing above ground dry matter at 15 days interval from 30 DAT to harvest. The samples excluding roots were dried at a temperature of 72 $^0$C for 48 hours in hot air oven. These dry matters results were used to calculate the above ground dry matter in kg ha$^{-1}$.

**3.6 Yield attributing characters**

**3.6.1 Effective tillers per square meter**

The same plants, used to count number of tillers per hill, were used to count the effective tillers per hill at harvest and this result was used for calculating effective tillers per square meter.

**3.6.2 Thousand grains weight (Test weight)**

Thousand grains were selected randomly from the grain yield of each plot and weighed with the help of electronic balance at about 14% moisture. The test weight is expressed in gram.

**3.6.3 Sterility percent**

The sterility percentage was worked out from the unfilled and total grains as follows:

$$\text{Sterility percentage} = \frac{\text{No. of unfilled grains}}{\text{Total no. of grains}} \text{ x } 100$$

### 3.6.4 Panicle weight and number of filled grains per panicle

Ten panicles were randomly taken and weighed in electronic balance and average weight was expressed in g. The grains from ten panicles, used to take panicle weight, were separated manually and filled and unfilled grains were counted and recorded on individual panicle basis.

### 3.6.5 Panicle length

The length of the panicle was taken from the same randomly selected ten panicles, used for counting the number of grains, and mean was calculated to determine the per panicle length and expressed as cm.

## 3.7 Phenological observations

Randomly selected ten hills of each plot were tagged from net plot for taking records of various phenological observations. For deciding calendar days required for attaining phenological stages (panicle initiation, booting, heading, anthesis and physiological maturity), approximately 75% attainment of each stage was supposed to be completion of that particular stage. The data recorded for each stage were expressed as days after sowing (DAS).

## 3.8 Growing degree days (GDD)

For estimating GDD, maximum and minimum temperature recorded during the experimental period was used. The GDD for each treatment was calculated based on formula suggested by Rajput *et al.* (1987).

According to Rajput et al. (1987):

$$\text{Growing degree days (GDD)} = \sum_{i=1}^{n} \left[\frac{(\text{Tmax} + \text{Tmin})}{2} - \text{Tb}\right]$$

Where, Tmax and Tmin are maximum and minimum temperatures of the day, respectively and Tb is the base temperature for rice crop which is 10 $^{0}$C i.e. below this temperature, there is no crop growth.

**3.9 Heat use efficiency (HUE)**

The HUE was calculated based on formula suggested by Rajput *et al.* (1987). According to Rajput et al. (1987):

$$\text{Heat use efficiency (HUE)} = \frac{\text{Grain yield}}{\text{Accumulated heat units}}$$

Where grain yield is expressed in kg $ha^{-1}$ and accumulated heat units is expressed in $^{0}$C.

**3.10 Grain and straw yields**

The net plot of 5.5 $m^2$, 6.72 $m^2$ and 6.84 $m^2$ for SRI, ICM and conventional management practices were harvested and grain and straw yields record was taken. The crop was first dried in the sun up to 3 days in the field and then threshed manually and cleaned and at last final weight was taken. The grain yield per hectare was computed for each treatment from the yield of net plot area. Digital moisture meter was used to record the moisture percentage of the grain. Finally grain yield was adjusted at 14% moisture using the formula as suggested by Paudel (1995).

$$\text{Grain yield (kg ha}^{-1}\text{) at 14\% moisture} = \frac{(100\text{-MC}) \times \text{net plot yield (kg)} \times 10000\ (\text{m}^2)}{(100\text{-}14) \times \text{net plot area (m}^2)}$$

Where, MC is the moisture content in percentage of the grains.

Straw yield was also recorded from the rows of net plot and then transferred into hectare.

### 3.11 Harvest index (HI)

Harvest index (HI) was computed by dividing grain yield with the total dry matter yield as per the following formula:

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{(\text{Grain yield} + \text{straw yield})}$$

### 3.12 Economic analysis

#### 3.12.1 Cost of cultivation

All the cost of cultivation was worked out on the basis of cost incurred according to the prevailing market price for different inputs, laborers, machines, fertilizers and others.

#### 3.12.2 Gross returns

The grain yield and straw yield was converted into gross return (NRs. $ha^{-1}$) based on the prevailing market price of the producers.

#### 3.12.3 Net returns

Net returns (NRs. $ha^{-1}$) for each plot was calculated by deducting the cost of cultivation from the gross return obtained. It is the one of good indicator of suitability of the cropping system as it represents the actual income to the farmer.

#### 3.12.4 Benefit cost ratio

Benefit cost ratio (B: C ratio) was calculated by dividing the gross return with the cost of cultivation (Reddy and Reddi, 2005).

### 3.13 Statistical analysis

Analysis of variance (ANOVA) for all recorded parameters were done using MSTAT-C, computer based program. All analyzed data were subjected to both Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT) for mean comparison where ever necessary at 5% significance level, as suggested by Gomez and Gomez (1984). A simple correlation and regression analysis was also run between selected parameters. Microsoft word 2010 was used for word processing; MS excels for tables, graphs and simple statistical analysis. SPSS was used for the correlation analysis.

**3.14 Simulation modeling**

To understand the impact of different agronomic performance and climate change parameter on rice, the CSM-CERES-Rice model was calibrated validated and sensitivity of the model to various agronomic and climatic parameters was performed.

**3.14.1 Data requirement for model evaluation**

CSM-CERES-Rice requires a well-defined set of inputs to simulate actual crop conditions (Benioff and Smith, 1994). These include soil and weather conditions, genetic coefficients, planting details, and irrigation and fertilizer schedules. The minimum data requirements for operation, calibration, and validation of these models (Hunt and Boote, 1994) are described in (Appendix 19). While data requirements depend upon the modeling objectives, larger quantities of accurate data will increase the model accuracy by avoiding parameter and equation based assumptions made by model (Timsina*et al.*, 1995). Descriptions of File-X, File-A, File-T, File-S and File-W prepared for the rice experiments are given in (Appendix 20, 21, 23, 22 and 24, respectively) DSSAT format.

**3.14.2 Model calibration**

Calibration is the adjustment of parameters to ensure simulated values compare well with observed values (Timsina and Hympherys, 2003). Calibration can be done for a range of plant and soil parameters; of particular importance are the genetic coefficients, which describe the duration of growth stages in growing degree days for a particular variety.

CERES- Rice uses eight genetic coefficients; four genetic coefficients are related to the plant development (P1, P2R, P5 and P2O). To estimate the genetic coefficient, the information from the four rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) with SRI management practice, were used. The information collected from the field experimentation on average thermal requirement to reach the anthesis and physiological maturity dates were used. The remaining four genetic coefficients are associated with grain yield (G1, G2, G3 and G4) were successively estimated and found to be nearly equal to the observed yield.

### 3.14.3 Model validation and evaluation

Validation of the model involves comparison of predicted and simulated data from crops that were not used for the calibration. The model were evaluated using the root mean sum square (RMSE) and index of agreement (d-stat) statistics (Willimott, 1982). The d-stat of a 'good' model should approach unity and the RMSE approach zero. The RMSE is considered the 'best' overall measure of model performance as it summarizes the mean difference in the units of observed and predicted values (Toit and Toit, 2003).

Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 with ICM and conventional management practices were used to validate the model. The parameters used for the validation of CERES-Rice were anthesis date, physiological maturity date, grain yield and tops weight at maturity.

### 3.14.4 Sensitivity analysis

Several parameters were chosen for practicing the sensitivity of CERES-Rice. The treatments used for the sensitivity analysis were Sukkha-3, Sukkha-4 and Hardinath-2 with ICM management practice and Sukkha-5 with conventional management practice.

Similarly, simulation to climate change parameter was accomplished by using the environmental modification section of X-build. For increase or decrease in maximum and minimum temperature by 4$^{o}$C, increase or decrease in solar radiation by 1 MJ m$^{-2}$ day$^{-1}$ and increase of $CO_2$ concentration by 20 ppm, the sensitivity analysis was done for each rice cultivar.

# 4 RESULTS AND DISCUSSION

The result obtained during the experiment is presented in this chapter with the help of tables and figures wherever necessary. The result obtained are discussed with possible reasons and supported with related literature.

## 4.1 Statistical analysis

### 4.1.1 Grain yield

The data on the grain yield of rice is presented in Table 5. Grain yield of rice was significantly influenced by management practices, whereas cultivars and interactions of cultivars and management practices did not significantly influence the grain yield.

The grain yield of SRI management practice (5.28 t $ha^{-1}$) was significantly higher than conventional management practice (4.49 t $ha^{-1}$), but was statistical at par with ICM management practice (4.73 t $ha^{-1}$). The grain yield of ICM was also significantly higher than conventional management practice. The higher grain yield of SRI management practice was because of higher number of effective tillers than ICM and conventional management practices (Table 6). Panicle weight, panicle length and filled grains per panicle of SRI management practice were also higher than ICM and conventional management practices (Table 6). Further, sterility percentage was the lowest in SRI than other management practices (Table 6). Higher number of effective tillers, panicle weight and filled grains per panicle were reported in SRI than conventional management practice (Subbiah *et al.*, 2006; Krishna *et al.*, 2008; Rao *et al.*, 2013; Islam *et al.*, 2014a; Ahmed *et al.*, 2015; Jana *et al.*, 2015). The higher grain yield of SRI was also due to higher LAI as compared to other management practices. The grain yield of rice is also determined by assimilates deposited mainly in vegetative stage, which is directly contributed by leaf area. Carbohydrates produced before heading mainly accumulate in the leaf sheath and stem and translocate to the panicles during grain filling (Fageria, 2007). The contribution of carbohydrates produced before heading to the final grain yield appeared to be in range of 20-40 % (Murata and Matsushima, 1975).

Table 5. Grain yield, straw yield and harvest index of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Grain yield, straw Yield and Harvest Index | | |
|---|---|---|---|
| | Grain yield (t $ha^{-1}$) | Straw Yield (t $ha^{-1}$) | Harvest Index (%) |
| Management | | | |
| SRI | 5.28 [a] | 5.12 [a] | 46.96 |
| ICM | 4.73 [ab] | 4.73 [b] | 46.14 |
| CON | 4.49 [b] | 4.06 [c] | 49.02 |
| SEm (±) | 0.145 | 0.057 | 0.885 |
| LSD (0.05) | 0.57 | 0.23 | ns |
| Cultivars | | | |
| Sukkha-3 | 4.79 | 5.21 [a] | 44.06 |
| Sukkha-4 | 4.73 | 4.43 [b] | 47.94 |
| Sukkha-5 | 5.16 | 4.49 [b] | 50.02 |
| Hardinath-2 | 4.64 | 4.42 [b] | 47.48 |
| SEm (±) | 0.236 | 0.108 | 1.30 |
| LSD (0.05) | ns | 0.37 | ns |
| CV (%) | 10.81 | 5.1 | 6.7 |
| Grand Mean | 4.83 | 4.64 | 47.37 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

It was revealed that SRI practice produced 17.49% more yield than conventional practice. Although SRI and ICM practices were statistical similar, SRI produced 11.63% more yield than ICM practice. Moreover, ICM also produced 5.35 % more grain yield as compared to conventional management practice. The increase in grain yield of 11.8 % was reported under SRI management practice over conventional (Mahajan and Sarao, 2009). The contributions of SRI to yield increase were found to be maximum, providing 143 %

yield increase when quality seed used alone, and up to 253% increase when combined with quality seeds and a good rice variety (Kabir, 2006). Similarly, increase in grain yield under SRI and ICM management practices were 209.9 % and 185.4 % higher, respectively over conventional management practices (Islam *et al.*, 2014a). Moreover, 100-200 % increase in grain yield was also reported under SRI compared to conventional management practice (Munda *et al.*, 2012).

The grain yield of all cultivars was statistically similar. However, the mean grain yield was the highest (5.16 t $ha^{-1}$) for Sukkha-5 and the lowest was (4.64 t $ha^{-1}$) for Hardinath-2. The interaction of cultivars and management practices was also found non-significant. However, the highest mean grain yield (5.73 t $ha^{-1}$) was observed in Sukkha-5 with SRI practice, followed by Sukkha-3 with SRI practice (5.35 t $ha^{-1}$). The lowest mean grain yield (4.20 t $ha^{-1}$) was found in Hardinath-2 with conventional practice.

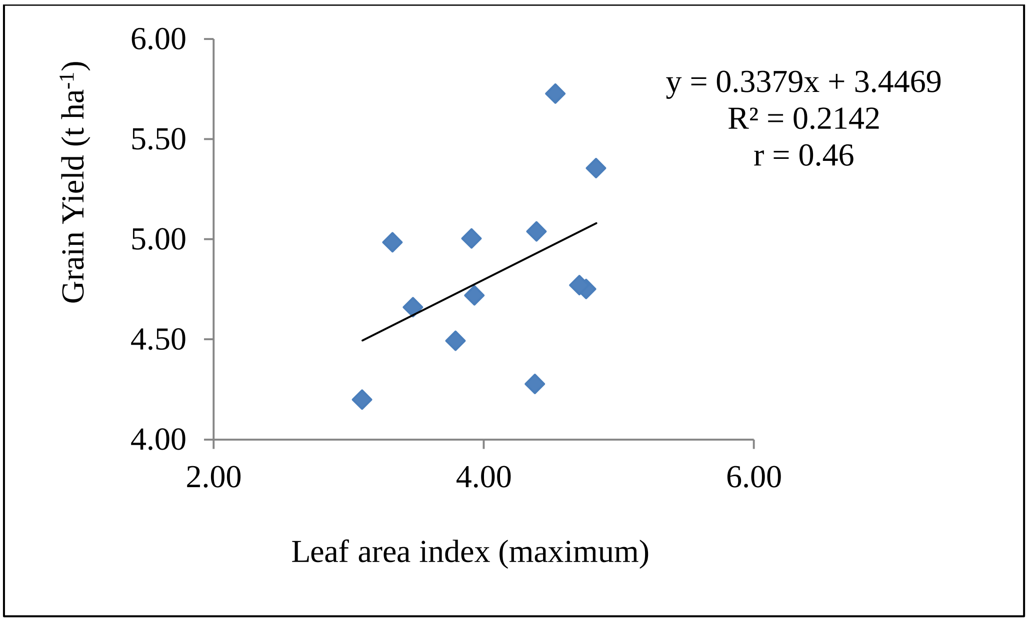


Figure 6. Linear regression between grain yield and leaf area index (maximum)

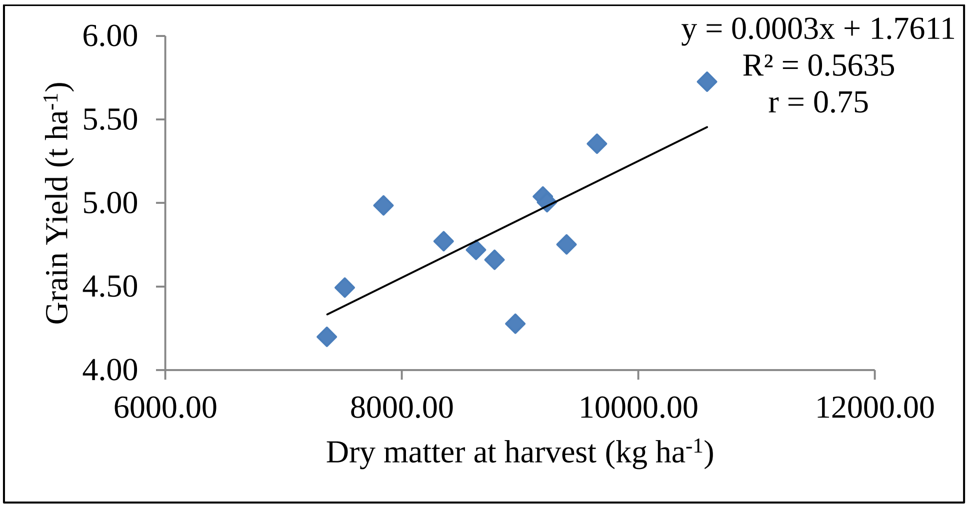


Figure 7. Linear regression between grain yield and dry matter at harvest

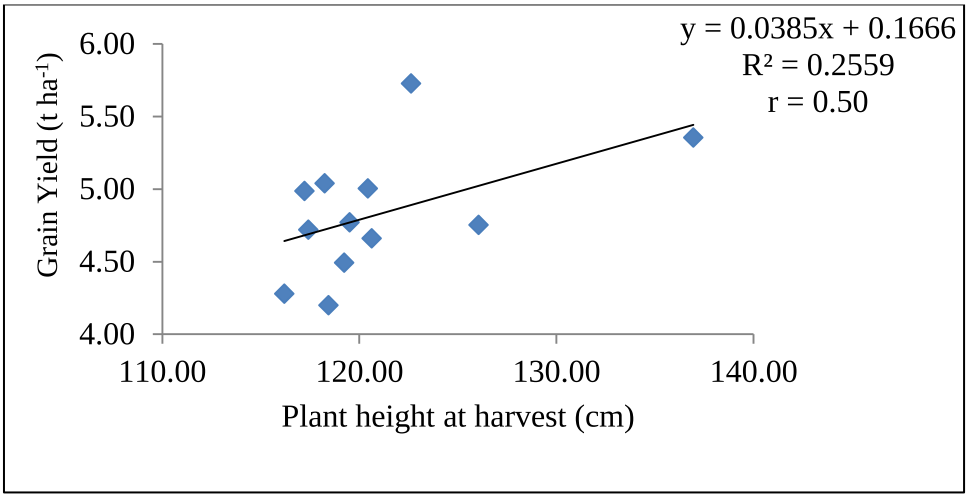


Figure 8. Linear regression between grain yield and plant height at harvest

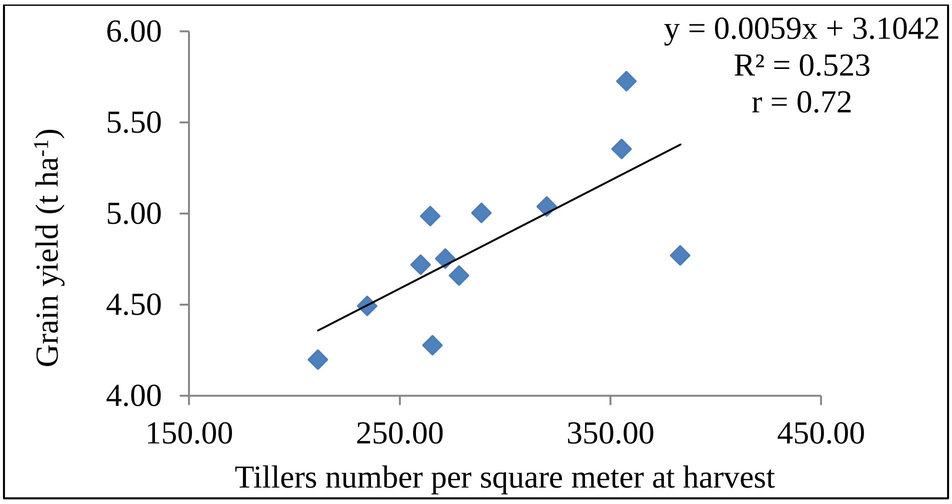


Figure 9. Linear regression between grain yield and tillers number per square meter

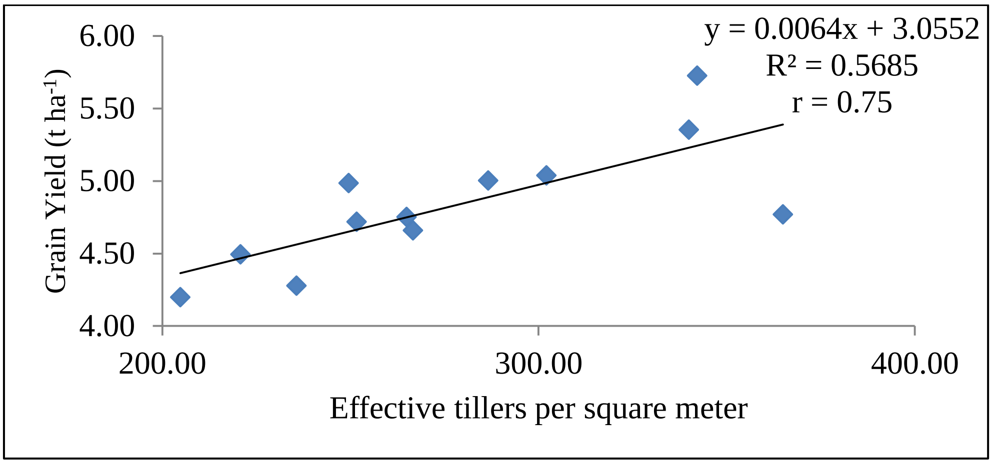


Figure 10. Linear regression between grain yield and effective tillers per square meter

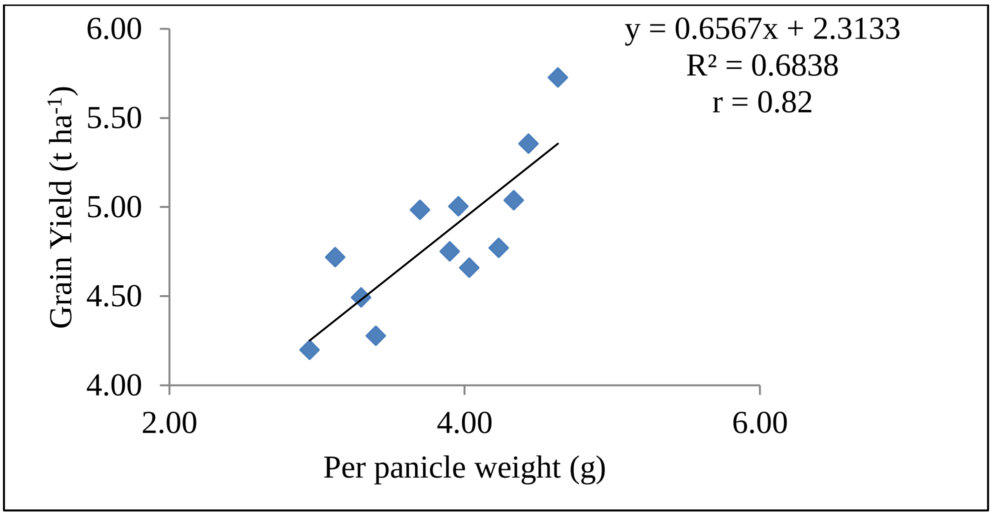


Figure 11. Linear regression between grain yield and per panicle weight

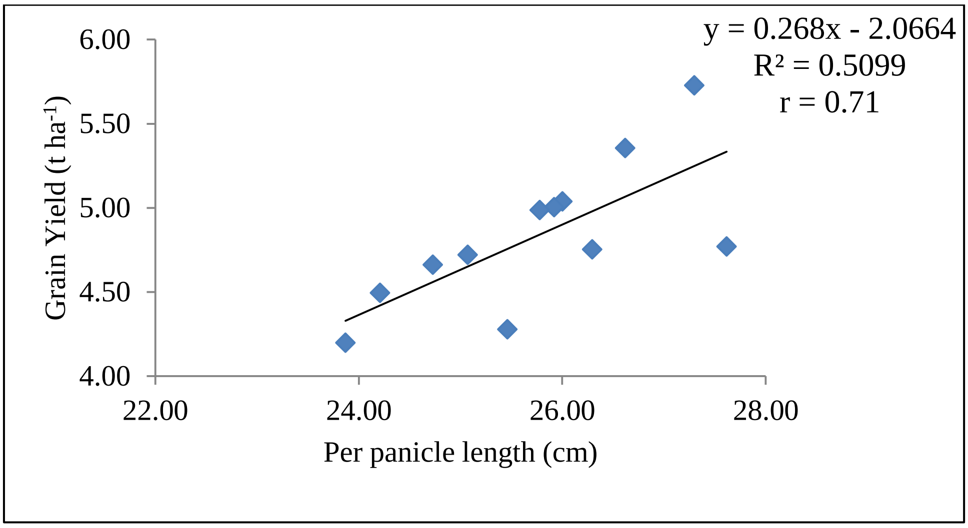


Figure 12. Linear regression between grain yield and per panicle length

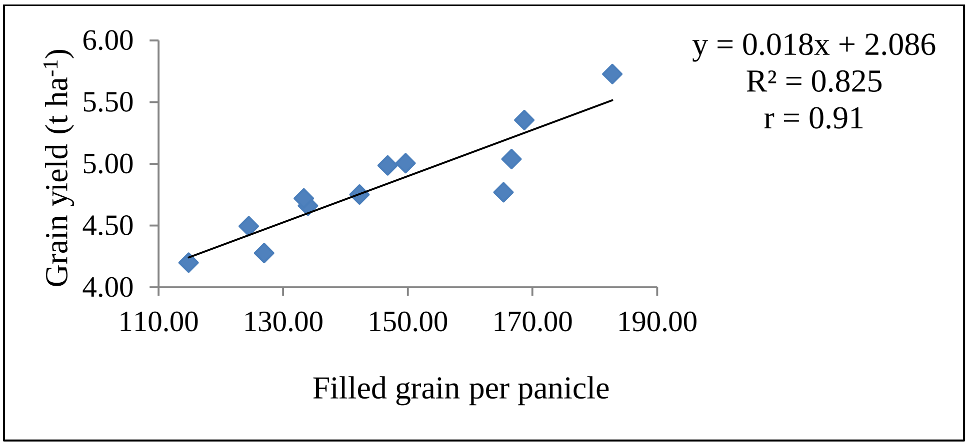


Figure 13. Linear regression between grain yield and filled grain per panicle

### 4.1.2 Straw yield

The straw yield of rice was significantly influenced by management practices, cultivars and their interactions (Table 5). It was found that the straw yield of SRI practice (5.12 t $ha^{-1}$) was significantly higher than ICM (4.73 t $ha^{-1}$) and conventional practices (4.06 t $ha^{-1}$). The straw yield of ICM practice was also significantly higher than conventional practice. This might be due to longer plant height in SRI management practice. Moreover, early vigorous growth due to wider spacing in SRI resulted treatment less competition in space, nutrition and other factors for growth might have resulted higher straw yield. The significant higher straw yield in SRI than in conventional management practices was also reported by Wijebandara *et al.* (2008) and Jeyapandiyan and Lakshmanan (2014). Further, the higher straw yield in SRI might also be due to higher number of tillers in SRI than other management practices (Wijebandara *et al.*, 2008).

The straw yield of Sukkha-3 (5.21 t $ha^{-1}$) was significantly higher than other varieties, whereas the straw yield of other cultivars were at par (Table 5). Higher straw yield of Sukkha-3 might be due to longer plant height of this cultivar. Higher straw yield in the cultivars with longer plant height was also reported by Haque and Pervin (2015).

Higher dry matter accumulation in Sukkha-3 might also had contributed to it's higher straw yield.

There was significant influence of interaction of cultivars and management practices in straw yield. The mean straw yield was found highest in Sukkha-5 with SRI (5.66 t $ha^{-1}$), followed by Sukkha-3 with ICM practices (5.31 t $ha^{-1}$). The lowest mean straw yield (3.56 t $ha^{-1}$) was observed in Sukkha-5 with conventional practice (Appendix 9).

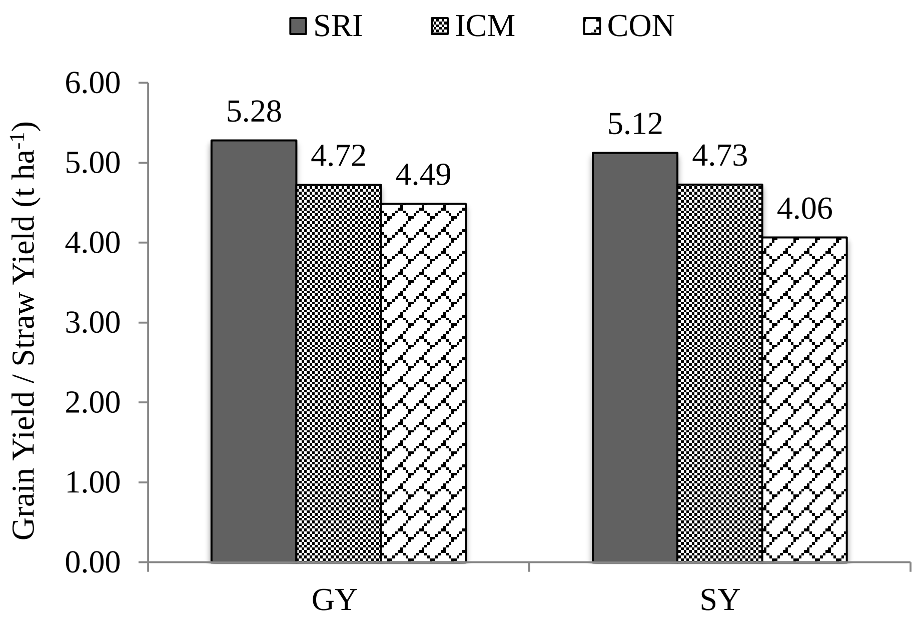


Figure 14. Comparison of grain and straw yields of three management practices in rice

### 4.1.3 Harvest Index

The harvest index was not significantly influenced by management practices. However, the highest mean harvest index was observed in conventional practice (49.02%), followed by SRI (46.96%) and ICM (46.14%), respectively.

The harvest index of all cultivars was statistically similar. However, the mean harvest index was highest (50.02%) for Sukkha-5 and the lowest was (44.06%) for Sukkha-3.

The significant interaction effect of cultivars and management practices was observed in harvest index. The highest mean harvest index (54.75%) was observed in Sukkha-5 with conventional practice, followed by Sukkha-4 with conventional practice (51.33%). The lowest mean harvest index (41.03%) was found in Sukkha-3 with conventional practice (Appendix 9).

### 4.1.4 Yield attributes

#### 4.1.4.1 Effective tillers per square meter

The number of effective tillers per square meter among the management practices was significantly different with the highest value in SRI (317.7) and the lowest in conventional (227.7). It was found that the number of effective tillers per square meter in ICM (287.1) was at par with effective tillers number per square meter of SRI, but was significantly higher than conventional management practice (Table 6). SRI practice had higher tiller producing capacity as compared to other management practices. It was evident that higher grain yield obtained from SRI was mainly owning to higher number of effective tillers per square meter. Higher number of effective tillers per square meter in SRI might be due to wider spacing in SRI which results less competition in space, nutrition and other factors for growth, which had helped for vigorous root growth and more tillering. Higher number of effective tillers per square meter in SRI was agreed by earlier experiments (Subbiah *et al.*, 2006; Wijebandara *et al.*, 2008; Geethalakshmi *et al.*, 2011; Islam *et al.*, 2014a; Ahmed *et al.*, 2015).

The number of effective tillers per square meter among the cultivars was statistically similar, with the highest in Sukkha-5 (318.9) and the lowest in Hardinath-2

(247.7). Similarly, interaction of cultivars and management practices has no influence on effective tillers per square meter. However, the highest mean of effective tillers number per square meter was found in Sukkha-5 with ICM management practice (365.0) and the lowest mean in Hardinath-2 with conventional management practice (204.8). There was positive correlation between effective tillers per square meter with r= 0.75 and regression line suggests that 56.8 % variation in grain yield (Figure 10) is due to effective tillers per square meter ($R^2$= 0.568).

#### 4.1.4.2 Panicle length

The length of panicle was significantly influenced by cultivars and management practices. The longest and the shortest panicle length were observed in SRI (26.46 cm) and conventional (24.83 cm) management practices, respectively. Moreover, the panicle length in SRI was also highly significant than ICM (25.93 cm), and the panicle length in ICM was also highly significant than conventional management practice. Longer panicle length in SRI was also reported by earlier researchers (Rahman *et al.*, 2006; Kumar *et al.*, 2006; Barla and Kumar, 2011; Jana *et al.*, 2015; Kunnathadi *et al.*, 2015). Similarly, the longest panicle length was observed in Sukkha-5 (26.90 cm) (Table 6), which was at par with panicle length of Sukkha-3 (26.13 cm). The shortest panicle length was observed in Hardinath-2 (24.95 cm), which was at par with panicle length of Sukkha-4 (24.98 cm). However, interaction of cultivars and management practices did not significantly influenced on panicle length, with the longest and the shortest mean panicle length in Sukkha-5 with ICM (27.62 cm) and in Hardinath-2 with conventional (23.87 cm) management practices, respectively.

#### 4.1.4.3 Panicle weight

Panicle weight of rice was significantly influenced by cultivars and management practices. The highest and the lowest panicle weight were observed in SRI (4.34 g) and conventional (3.34 g) management practices, respectively. Moreover, the panicle weight in ICM was statistically at par with SRI and conventional management practices. Higher panicle weight in SRI management practice was also reported by Subbiah *et al.* (2006), Sekhar *et al.* (2009) and Rao *et al.* (2013). Similarly, the highest panicle weight was observed in Sukkha-5 (4.19 g) (Table 6), which was at par with panicle weight of Sukkha-4 (3.89 g) and Sukkha-3 (3.91 g). The lowest panicle weight was observed in Hardinath-2 (3.34 g). However, interaction of cultivars and management practices had no influence on panicle weight, with highest and the lowest mean panicle weight in Sukkha-5 with SRI (4.63 g) and in Hardinath-2 with conventional (2.95 g) management practices, respectively.

**4.1.4.4 Filled grains per panicle**

The influence of management practices on filled grain per panicle was highly significant, with the highest mean in SRI (167.0) and the lowest mean in conventional management (128.3) (Table 6). The filled grains per panicle in SRI were also significantly higher than ICM (143.8). Higher filled grains per panicle in SRI might be due to better translocation of carbohydrates, produced before heading and accumulated in leaf sheath and stem, to the panicles during grain filling. Moreover, optimum plant population and geometry under SRI might have led to availability of more resources to the plants that resulted in higher filled grain per panicle. Increased number of filled grains per panicle has been attributed to an increased dry matter translocation percentage from vegetative organs to the grains (Wang *et al.*, 2002). Higher filled grains per panicle in SRI was also supported by various previous experiments (Wijebandara *et al.*, 2008; Geethalakshmi *et al.*, 2011; Islam *et al.*, 2014a; Ahmed *et al.*, 2015).

The filled grains per panicle were not influenced by cultivars. However, the highest mean was recorded in Sukkha-5 (165.0) and the lowest in Hardinath-2 (132.6). Similarly, the interaction of cultivars and management practices was also insignificant, with the highest mean in Sukkha-5 with SRI (182.83) and the lowest in Hardinath-2 with conventional management practice (114.87). It was revealed that there was positive correlation between filled grain per panicle and grain yield (r= 0.91) and 82.5 % variation in grain yield (Figure 13) was due to filled grain per panicle ($R^2$= 0.825).

Table 6. Yield attributes of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Effective tillers (per $m^2$) | Length (cm $panicle^{-1}$) | Weight (g $panicle^{-1}$) | Filled grain number ($panicle^{-1}$) | Sterility (%) | Test weight (g) |
|---|---|---|---|---|---|---|
| Management | | | | | | |
| SRI | 317.7 $^{a}$ | 26.46 $^{a}$ | 4.340 $^{a}$ | 167.0 $^{a}$ | 14.97 $^{b}$ | 24.12 |
| ICM | 287.1 $^{a}$ | 25.93 $^{b}$ | 3.823 $^{ab}$ | 143.8 $^{b}$ | 15.13 $^{b}$ | 22.76 |
| CON | 227.7 $^{b}$ | 24.83 $^{c}$ | 3.337 $^{b}$ | 128.3 $^{b}$ | 16.23 $^{a}$ | 22.23 |
| SEm(±) | 13.990 | 0.066 | 0.141 | 3.940 | 0.253 | 1.012 |
| LSD(0.05) | 54.94 | 0.261 | 0.5541 | 15.48 | 0.993 | ns |
| Cultivars | | | | | | |
| Sukkha-3 | 280.2 | 26.13 $^{a}$ | 3.911 $^{a}$ | 146.0 | 15.23 | 23.34 |
| Sukkha-4 | 263.2 | 24.98 $^{b}$ | 3.889 $^{a}$ | 141.7 | 15.09 | 22.49 |
| Sukkha-5 | 318.9 | 26.90 $^{a}$ | 4.189 $^{a}$ | 165.0 | 15.48 | 24.17 |
| Hardinath-2 | 247.7 | 24.95 $^{b}$ | 3.344 $^{b}$ | 132.6 | 15.97 | 22.14 |
| SEm(±) | 18.26 | 0.258 | 0.1456 | 6.270 | 0.277 | 0.974 |
| LSD(0.05) | ns | 0.89 | 0.50 | ns | ns | ns |
| CV (%) | 10.4 | 4.2 | 12.0 | 12.1 | 5.7 | 9.6 |
| Grand Mean | 277.5 | 25.74 | 3.833 | 146.4 | 15.44 | 23.03 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

**4.1.4.5 Sterility percentage**

The highest value of sterility percentage was found in conventional (16.23%), which was significantly higher than ICM (15.13%) and SRI (14.97%) management practices. The sterility percentage of ICM and SRI management practices were statistically at par. Lower sterility percentage in SRI might be due to favorable growth and better translocation of assimilates to the sink as it was revealed by sound filing of grains. Similar result was reported by Rao *et al.* (2013).

The sterility percentage was not significantly influenced by cultivars. However, the highest sterility percentage was found in Hardinath-2 (15.97%) and the lowest in Sukkha-4 (15.09%).

The interaction of cultivars and management practices had influence in sterility percentage. The highest mean of sterility percentage was found in Sukkha-4 with conventional (18.21%), followed by Hardinath-2 with ICM management practice (16.40%). The lowest mean was found in Sukkha-4 with SRI management practice (13.37%).

**4.1.4.6 Test weight**

There was no influence in test weight by cultivars, management practices and their interactions. Within cultivars, the highest value was observed in Sukkha-5 and the lowest in Hardinath-2 whereas within management practices, the highest mean of test weight was observed in SRI and the lowest in conventional management practices. No difference in test weight among the management practices was reported by Kunnathadi *et al.* (2015). Similarly, the highest mean test weight was found in Sukkha-5 with SRI and the lowest in Hardinath-2 with conventional management practices.

**4.1.5 Biometric observation**

**4.1.5.1 Plant height**

The management practices do not have significant influence in plant height except at 75 DAT and at harvest. SRI had the higher plant height at all DAT, but was statistically different at 75 DAT and at harvest. At harvest, SRI had the highest plant height (124.56

cm) followed by ICM (120.91 cm) and conventional management practices (117.77 cm). The plant height of ICM was significantly higher than conventional, but at par with plant height of SRI. The longer plant height in SRI compared to conventional practice might be due to the wider spacing which would have helped in better availability of resources and increased photosynthesis, resulting better growth. Taller plant height in SRI management practice compared with other management practices was reported by Wijebandara *et al.* (2008), Geethalakshmi *et al.* (2011), Jana *et al.* (2015) and Kunnathadi *et al.* (2015). Higher number of functional leaves, more leaf area and higher number of tillers hill$^{-1}$ at wider spacing increased the photosynthetic rate leading to taller plants (Shrirame *et al.*, 2000).

Plant height was not influenced by cultivars till 45 DAT and was significantly different at 60 DAT and 75 DAT. Again, at 90 DAT and at harvest, plant height among cultivars was at par. Sukkha-3 variety was the tallest variety at all DAT which was significantly different than Sukkha-4 and Sukkha-5 at 60 DAT, but was statistically at par with Hardinath-2 at 60 DAT. At 75 DAT, the plant height of Sukkha-3 was significantly higher than other cultivars. The difference in plant height according to cultivars was reported by Haque and Pervin (2015) and Ahmed *et al.* (2015).

Plant height was not influenced by interaction of cultivars and management practices till 60 DAT and was significantly influenced only at 75 DAT, 90 DAT and at harvest. Sukkha-3 with SRI management practice was the tallest at 75 DAT, 90 DAT and at harvest. Similar result was also reported by Ahmed *et al.* (2015). There was positive correlation between plant height at harvest and grain yield (r= 0.50) and regression line suggesting us that 25.5 % variation in grain yield was due to plant height at harvest ($R^2$= 0.255) (Figure 8).

Table 7. Plant height various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Plant height (cm) | | | | | |
|---|---|---|---|---|---|---|
| | 30DAT | 45DAT | 60DAT | 75DAT | 90DAT | At Harvest |
| Management | | | | | | |
| SRI | 44.39 | 87.64 | 106.95 | 124.24 [a] | 125.94 | 124.56 [a] |
| ICM | 43.91 | 84.33 | 105.03 | 119.85 [ab] | 122.07 | 120.91 [ab] |
| CON | 43.72 | 83.64 | 102.57 | 115.43 [b] | 117.55 | 117.77 [b] |
| SEm (±) | 0.530 | 0.934 | 0.951 | 1.352 | 1.750 | 1.219 |
| LSD (0.05) | ns | ns | ns | 5.31 | ns | 4.79 |
| Cultivars | | | | | | |
| Sukkha-3 | 44.81 | 87.84 | 114.83 [a] | 124.43 [a] | 126.40 | 126.40 |
| Sukkha-4 | 43.87 | 85.12 | 98.10 [b] | 118.52 [b] | 119.37 | 119.37 |
| Sukkha-5 | 42.66 | 80.58 | 93.22 [b] | 117.65 [b] | 119.79 | 119.79 |
| Hardinath-2 | 44.69 | 87.26 | 113.25 [a] | 118.76 [b] | - | 118.76 |
| SEm (±) | 0.698 | 1.604 | 1.742 | 1.118 | 1.869 | 1.723 |
| LSD (0.05) | ns | ns | 6.03 | 3.87 | ns | ns |
| CV (%) | 3.3 | 2.8 | 5.1 | 2.8 | 3.1 | 3.0 |
| Grand Mean | 44.01 | 85.20 | 104.85 | 119.84 | 121.85 | 121.08 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05. The symbol '-' in column for Hardinath-2 at 90 DAT means this cultivar was harvested prior to 90 DAT.

#### 4.1.5.2 Number of tillers per square meter

A close scrutiny of data presented in Table 8 revealed that the tillers number per square meter was significantly influenced by cultivars, management practices and their interactions in early days of transplanting, whereas at harvest, the tillers per square meter was not influenced by any of above. Among management practices, SRI produced higher number of tillers at all DAT. Higher tiller number in SRI might be due to wider spacing in SRI, resulting less competition in space, nutrition and other factors for growth, which had helped for vigorous root growth and more tillering. Wider spacing reduces inter-plant competition for nutrients, water, light and air, which accounts for significant enhancement in the performance of individual hills under SRI (Thakur *et al.*, 2010). Further, alternate wetting and drying of soil in SRI might have energized the tillering potential of plants under SRI. Planting seedlings of less than 15 days old at wider spacing, not only gives more than 10 days for tillering, but also gives the seedlings a large zone from which to draw their nutrients (Thiyagarajan, 2006). However, the significant difference in tillers was found only at 30 DAT, 45 DAT, 60 DAT and 75 DAT. The highest number of tiller per square meter (456.6) was recorded at 30 DAT which was significantly higher than the number of tillers in ICM (398.3) and conventional (244.8) management practices. The highest number of tiller per square meter at 30 DAT might be due to active vegetative phase of crop at this period. Further, this might also be due to higher phytomers development efficiency of SRI at early stages of growth. Moreover, the tillers number per square meter was continuously decreased from 30 DAT which could be due to tillers mortality. Higher tillers number in SRI was also reported by various researchers earlier (Wijebandara *et al.*, 2008, Thakur *et al.*, 2010; Kunnathadi *et al.*, 2015).

It was observed that Sukkha-5 produced higher number of tillers at all DAT. However, the significant difference in tillers number was found only at 30 DAT, 45 DAT and 60 DAT. The highest number of tillers per square meter (384.9) was recorded at 30 DAT, which was significantly higher than the number of tillers in Sukkha-4 (363.8) and Hardinath-2 (340.6) and statistically at par with Sukkha-3 (377) at 30 DAT. The difference in number of tillers production among the varieties was attributed to varietal characteristics, which was also reported by Haque and Pervin (2015).

The interaction of cultivars and management practices has significant influence in tillers per square meter at 30 DAT, 45 DAT, 60 DAT and 90 DAT. The highest number of tillers per square meter at 30 DAT, 45 DAT, 60 DAT and 90 DAT was recorded in

Sukkha-4 with SRI (502.2), Sukkha-5 with ICM (473.3), Sukkha-5 with ICM (406.7) and Sukkha-5 with ICM (383.3), respectively and were significantly higher than other treatments. It was observed that there was positive correlation between number of tillers per square meter and grain yield (r= 0.72) and regression line shows that variation in the grain yield due to number of tillers was 52.3 % ($R^2$= 0.523) (Figure 9).

Table 8. Tillers number of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Tiller number (per $m^2$) | | | | | |
|---|---|---|---|---|---|---|
| | 30DAT | 45DAT | 60DAT | 75DAT | 90DAT | At Harvest |
| Management | | | | | | |
| SRI | 456.6 $^{a}$ | 395.0 $^{a}$ | 338.3 $^{a}$ | 337.7 $^{a}$ | 344.4 | 330.5 |
| ICM | 398.3 $^{b}$ | 382.9 $^{a}$ | 305.4 $^{b}$ | 305.0 $^{a}$ | 311.1 | 298.3 |
| CON | 244.8 $^{c}$ | 292.8 $^{b}$ | 251.7 $^{c}$ | 245.1 $^{b}$ | 254.9 | 244.0 |
| SEm (±) | 8.90 | 5.60 | 4.87 | 14.30 | 21.72 | 18.53 |
| LSD (0.05) | 34.94 | 21.98 | 19.11 | 56.13 | ns | ns |
| Cultivars | | | | | | |
| Sukkha-3 | 377.0 $^{ab}$ | 369.2 $^{b}$ | 315.5 $^{b}$ | 311.7 | 297.6 | 297.6 |
| Sukkha-4 | 363.8 $^{b}$ | 359.6 $^{b}$ | 279.5 $^{c}$ | 277.7 | 277.7 | 277.7 |
| Sukkha-5 | 384.9 $^{a}$ | 402.4 $^{a}$ | 344.1 $^{a}$ | 339.6 | 335.2 | 335.2 |
| Hardinath-2 | 340.6 $^{c}$ | 296.4 $^{c}$ | 254.8 $^{d}$ | 254.8 | - | 253.4 |
| SEm (±) | 5.69 | 5.71 | 6.38 | 20.07 | 21.27 | 18.19 |
| LSD (0.05) | 19.68 | 19.76 | 22.07 | ns | ns | ns |
| CV (%) | 6.4 | 6.6 | 5.2 | 11.7 | 9.3 | 11.6 |
| Grand Mean | 366.6 | 356.9 | 298.5 | 295.9 | 303.5 | 291.0 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05. The symbol '-' in column for Hardinath-2 at 90 DAT means this cultivar was harvested prior to 90 DAT.

#### 4.1.5.3 Leaf area index

Leaf area index was not influenced by cultivars, but was significantly influenced by management practices and their interactions. The highest LAI was recorded in SRI at all DAT with the highest at 60 DAT (4.26) which was significantly higher than conventional (3.60) at 60 DAT but was statistically similar with ICM (4.07) at 60 DAT.

Table 9. Leaf area index of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Leaf Area Index | | |
|---|---|---|---|
| | 30DAT | 45DAT | 60DAT |
| Management | | | |
| SRI | 2.05 [a] | 4.10 [a] | 4.26 [a] |
| ICM | 1.45 [b] | 3.85 [b] | 4.07 [a] |
| CON | 1.00 [c] | 2.68 [c] | 3.60 [b] |
| SEm (±) | 0.037 | 0.052 | 0.103 |
| LSD (0.05) | 0.15 | 0.21 | 0.41 |
| Cultivars | | | |
| Sukkha-3 | 1.73 | 3.93 | 4.57 |
| Sukkha-4 | 1.42 | 3.40 | 3.78 |
| Sukkha-5 | 1.44 | 3.52 | 3.98 |
| Hardinath-2 | 1.41 | 3.32 | 3.58 |
| SEm (±) | 0.074 | 0.129 | 0.215 |
| LSD (0.05) | ns | ns | ns |
| CV (%) | 8.6 | 7.6 | 7.0 |
| Grand Mean | 1.499 | 3.544 | 3.977 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

There was rapid increase in LAI from 30 DAT to 45 DAT. This might be due to rapid vegetative growth that takes place in plant. Moreover, there was slight increase in LAI from 45 DAT to 60 DAT and after this; LAI was found to be decreased. Higher LAI in SRI was also observed in various experiments carried out earlier (Shrirame *et al.*, 2000; Thakur *et al.*, 2010; Thakur *et al.*, 2011; Mohanty *et al.*, 2014; Ahmed *et al.*, 2015).

The interaction of cultivars and management practices showed that the maximum LAI was gained by Sukkha-3 (4.83) with SRI at 60 DAT, followed by Sukkha-3 (4.76) with ICM at 45 DAT. The lowest LAI was observed in Hardinath-2 (3.10) with conventional at 45 DAT. The higher LAI in Sukkha-3 might be due to greater plant height than other cultivars. The positive correlation (r= 0.46) between LAI maximum and grain yield was recorded (Figure 6) with 21.6 % variation in grain yield due to LAI maximum ($R^2$= 0.214).

**4.1.5.4 Dry matter**

Dry matter accumulation was significantly influenced by cultivars, management practices and their interactions (Table 10). Among management practices, SRI had higher dry matter accumulation at all DAT which was significantly higher than ICM and conventional. Dry matter accumulation in ICM was also significantly higher than conventional management practice. This might be due to higher LAI in SRI, followed by ICM and conventional management practices. Greater leaf area in SRI might have increased the photosynthetic rates leading to more dry matter accumulation. Further, taller plants and more number of tillers might have contributed to higher dry matter accumulation in SRI management practice. Higher dry matter accumulation in SRI was reported in various experiments carried out earlier (Wijebandara *et al.*, 2008; Thakur *et al.*, 2010; Mohanty *et al.*, 2014).

Dry matter accumulation was significantly influenced by cultivars till 60 DAT and later then this, it was statistically at par. The highest dry matter accumulation was observed in Sukkha-3 at all DAT which was significantly higher than other cultivars till 60 DAT. The lowest dry matter accumulation was recorded in Sukkha-5 till 60 DAT, Sukkha-4 at 75

DAT and Hardinath-2 at harvest. The higher dry matter accumulation in Sukkha-3 might be due to greater plant height and also higher LAI.

Table 10. Dry matter of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Dry matter (kg $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At Harvest |
| Management | | | | | | |
| SRI | 1889 [a] | 5017 [a] | 7667 [a] | 9109 [a] | 9319 [a] | 9664 [a] |
| ICM | 1260 [b] | 4784 [b] | 6995 [a] | 8091 [b] | 8644 [b] | 8791 [b] |
| CON | 908 [c] | 3384 [c] | 6093 [b] | 7403 [c] | 7997 [c] | 7924 [c] |
| SEm (±) | 12.7 | 40.3 | 209.6 | 165.1 | 145.2 | 105.8 |
| LSD (0.05) | 50.0 | 158.2 | 822.9 | 648.3 | 570.3 | 415.5 |
| Cultivars | | | | | | |
| Sukkha-3 | 1561 [a] | 4884 [a] | 7891 [a] | 8664 | 9053 | 9336 |
| Sukkha-4 | 1218 [b] | 4105 [b] | 6752 [b] | 7857 | 8347 | 8500 |
| Sukkha-5 | 1174 [b] | 3871 [b] | 6176 [c] | 8294 | 8560 | 8928 |
| Hardinath-2 | 1456 [a] | 4721 [a] | 6853 [b] | 7988 | - | 8409 |
| SEm (±) | 31.8 | 74.4 | 102.4 | 168.8 | 213.6 | 244.3 |
| LSD (0.05) | 110.1 | 257.6 | 354.4 | ns | ns | ns |
| CV (%) | 5.3 | 4.7 | 7.0 | 4.5 | 6.0 | 5.4 |
| Grand Mean | 1352 | 4395 | 6918 | 8201 | 8653 | 8793 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05. The symbol '-' in column for Hardinath-2 at 90 DAT means this cultivar was harvested prior to 90 DAT.

The interaction of cultivars and management practices revealed that the dry matter accumulation was significantly influenced by it. The highest dry matter accumulation was recorded in Hardinath-2 with SRI at 30 DAT, Sukkha-3 with SRI at 45 DAT and 60 DAT and Sukkha-5 with SRI at 75 DAT, 90 DAT and at harvest. Similarly, the lowest dry matter accumulation at 30 DAT, 45 DAT, 60 DAT, 75 DAT, 90 DAT and at harvest was recorded in Sukkha-5 with conventional, Sukkha-4 with conventional, Hardinath-2 with conventional, Sukkha-5 with conventional, Sukkha-4 with conventional and Hardinath-2 with conventional management practices, respectively.

There was rapid increase in dry matter accumulation from 30 DAT to 75 DAT in all varieties and in the management practices, rapid dry matter accumulation was observed from 30 DAT to 45 DAT. This might be due to rapid vegetative growth that occurs in plant. Moreover, it was observed that the positive correlation (r= 0.75) exist between dry matter accumulation at harvest and grain yield and regression line shows that variation in the grain yield due dry matter accumulation at harvest was 56.3 % ($R^2$= 0.563) (Figure 7).

### 4.1.6 Phenology

The data on phenology is presented in Table 11. The phenology in rice was highly influenced by varieties, management practices and their interactions.

#### 4.1.6.1 Panicle Initiation

Among management practices, SRI required the minimum days for panicle initiation (52.75 days), followed by ICM (55.50 days) and conventional (60.50 days), respectively. Similarly, the maximum days for panicle initiation was required by Sukkha-5 variety (61 days), followed by Sukkha-3 (59 days), whereas, Hardinath-2 variety required the minimum days (47.67 days) (Table 11). The interaction exhibited that the maximum and minimum days required for panicle initiation was observed in Sukkha-5 with conventional practice (65 days) and in Hardinath-2 with SRI (45 days) management practices, respectively (Appendix 10).

#### 4.1.6.2 Heading

Among management practices, SRI required the minimum days for heading (70.25 days), followed by ICM (75.50 days) and conventional (81.25 days), respectively. Similarly, the maximum days for heading was required by Sukkha-5 (83 days), followed by Sukkha-3 (78.33 days), whereas, Hardinath-2 required the minimum days (66 days) (Table 11). The interaction exhibited that the maximum and minimum days required for panicle initiation was observed in Sukkha-5 with conventional (90 days) and in Hardinath-2 with SRI (61 days) management practices, respectively (Appendix 10).

Table 11. Phenology of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Phenology | | |
|---|---|---|---|
| | Panicle initiation (DAS) | Heading (DAS) | Physiological maturity (DAS) |
| Management | | | |
| SRI | 52.75 [c] | 70.25 [c] | 107.50 [c] |
| ICM | 55.50 [b] | 75.50 [b] | 110.50 [b] |
| CON | 60.50 [a] | 81.25 [a] | 115.50 [a] |
| SEm (±) | 0.132 | 0.083 | 0.083 |
| LSD (0.05) | 0.52 | 0.33 | 0.33 |
| Cultivars | | | |
| Sukkha-3 | 59.00 [b] | 78.33 [b] | 114.00 [ab] |
| Sukkha-4 | 57.33 [b] | 75.33 [c] | 112.00 [b] |
| Sukkha-5 | 61.00 [a] | 83.00 [a] | 115.67 [a] |
| Hardinath-2 | 47.67 [c] | 66.00 [d] | 102.67 [c] |
| SEm (±) | 0.509 | 0.547 | 0.569 |
| LSD (0.05) | 1.76 | 1.89 | 1.97 |
| CV (%) | 1.1 | 0.6 | 0.3 |
| Grand Mean | 56.25 | 75.67 | 111.17 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

**4.1.6.3 Physiological maturity**

Among management practices, SRI required the minimum days to reach physiological maturity (107.50 days), followed by ICM (110.50 days) and conventional (115.50 days), respectively (Table 11). Early vigorous growth favored by wider spacing in

SRI and ICM might be the cause for early maturity of crop in these management practices as compared to conventional. Further, slow growth at early and vegetative stage might have caused the crop to require maximum days to reach physiological maturity. Similar result was also reported Krishna *et al.* (2008) and Rao *et al.* (2013). Further, 7-10 days earlier physiological maturity of crop under SRI and ICM over conventional management practice was reported by Islam *et al.* (2014a).

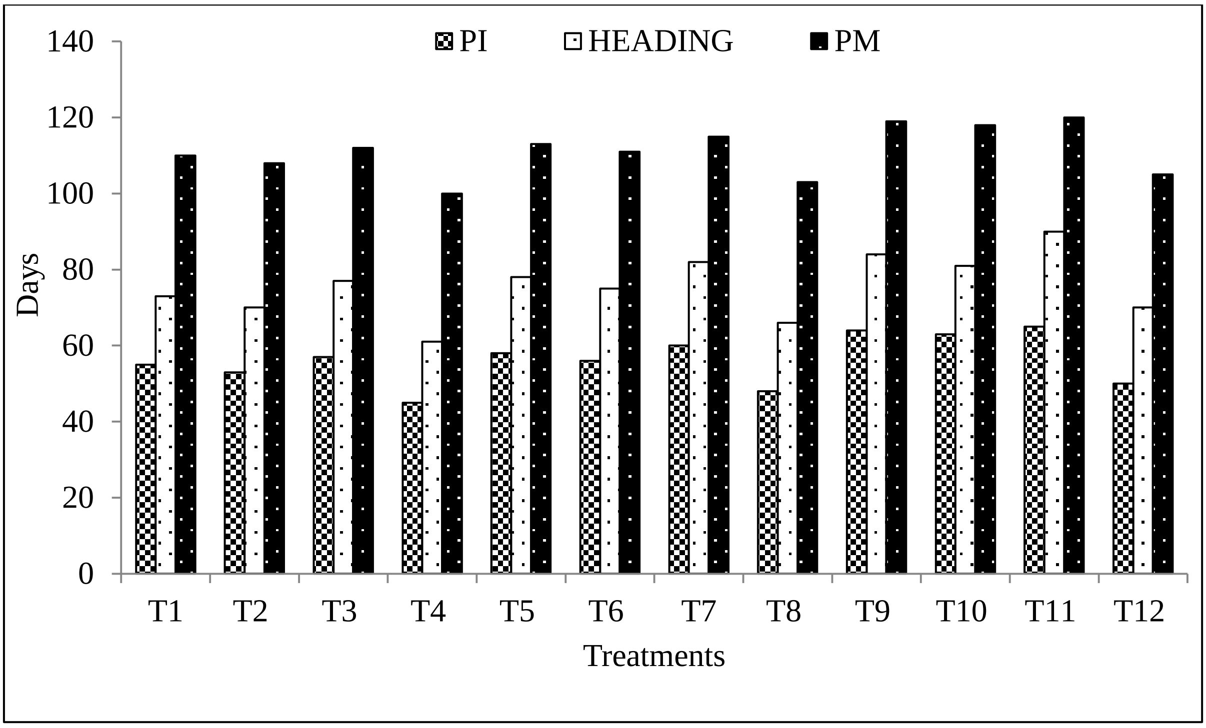


Figure 15. Phenology of different treatments

Similarly, it was revealed that the maximum days was required by Sukkha-5 (115.67 days) to reach it's physiological maturity (Table 11), followed by Sukkha-3 (114.00 days). Hardinath-2 variety required the minimum days (102.67 days) to reach it's physiological maturity. The difference in time required by varieties to reach physiological maturities was attributed to cultivar characters. Hardinath-2 matures early whereas Sukkha-5 is comparatively late cultivar. Moreover, short and dwarf structure during vegetative phase might also have contributed to maximum day's requirement for Sukkha-5 to reach physiological maturity.

The interaction exhibited that the maximum and minimum days required to reach physiological maturity was observed in Sukkha-5 with conventional (120.00 days) and in Hardinath-2 with SRI (100.00 days) management practices, respectively (Appendix 11).

#### 4.1.6.4 Growing Degree Days (GDD)

GDD requirement of rice to reach panicle initiation, heading and physiological maturity in Nawalparasi was significantly influenced by cultivars, management practices and their interactions (Table 12). Among management practices, conventional practice required the maximum GDD to reach panicle initiation (1459.44°C), heading (1915.24°C) and physiological maturity (2622.83°C) which was significantly higher than GDD requirement by SRI and ICM management practices to reach panicle initiation, heading and physiological maturity. Maximum GDD requirements by conventional practice, to reach each phenological stages, was natural, as this practice required the longest days to reach each phenological stages.

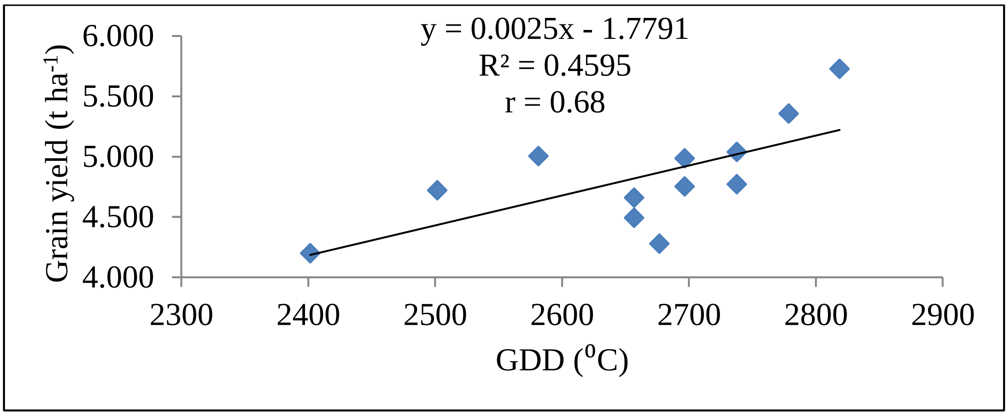


Figure 16. Linear regression between grain yield and GDD requirements to reach physiological maturity

Sukkha-5 required maximum GDD to reach panicle initiation (1431.32°C), heading (1909.20°C) and physiological maturity (2567.36°C). The GDD requirements by Sukkha-5 to reach heading and physiological maturity were significantly higher than GDD requirement by Sukkha-4 and Hardinath-2 cultivars, but were at par with GDD requirement by Sukkha-3 cultivar. Moreover, the GDD requirement by Sukkha-5 to reach panicle initiation was significantly higher than other varieties. The cultivar Hardinath-2 required the minimum GDD to reach panicle initiation (1143.51°C), heading (1449.21°C) and physiological maturity (2303.93°C).

Table 12. GDD requirements and HUE of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | GDD (˚C) | | | HUE |
|---|---|---|---|---|
| | PI | Heading | PM | |
| Management | | | | |
| SRI | 1215.39 [c] | 1599.38 [c] | 2349.45 [c] | 2.25 [a] |
| ICM | 1311.29 [b] | 1682.30 [b] | 2456.44 [b] | 1.93 [b] |
| CON | 1459.44 [a] | 1915.24 [a] | 2622.83 [a] | 1.71 [b] |
| SEm (±) | 1.758 | 19.230 | 1.663 | 0.058 |
| LSD (0.05) | 6.90 | 75.51 | 6.53 | 0.23 |
| Cultivars | | | | |
| Sukkha-3 | 1388.37 [b] | 1816.13 [ab] | 2533.65 [ab] | 1.91 |
| Sukkha-4 | 1351.62 [c] | 1754.68 [b] | 2500.01 b | 1.90 |
| Sukkha-5 | 1431.32 [a] | 1909.20 [a] | 2567.36 [a] | 2.02 |
| Hardinath-2 | 1143.51 [d] | 1449.21 [c] | 2303.93 [c] | 2.02 |
| SEm (±) | 10.414 | 29.670 | 11.192 | 0.101 |
| LSD (0.05) | 36.04 | 102.7 | 38.73 | ns |
| CV (%) | 1.07 | 4.02 | 0.25 | 10.76 |
| Grand Mean | 1328.71 | 1732.31 | 2476.24 | 1.963 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

The interaction of varieties and management practices had significant influence in GDD requirement by crop. It observed that the maximum GDD to reach panicle initiation, heading and physiological maturity was required by Sukkha-5 with conventional practice which was significantly higher than rest of all and the minimum GDD was required by Hardinath-2 with SRI practice to reach panicle initiation and physiological maturity, and Hardinath-2 with ICM practice to reach heading. Further, it was revealed that there was positive correlation (r=0.68) between GDD requirement to reach physiological maturity and grain yield (Figure 16) and regression line suggest that 45.9 % variation in grain yield was due to GDD requirement to reach physiological maturity ($R^2$= 0.459).

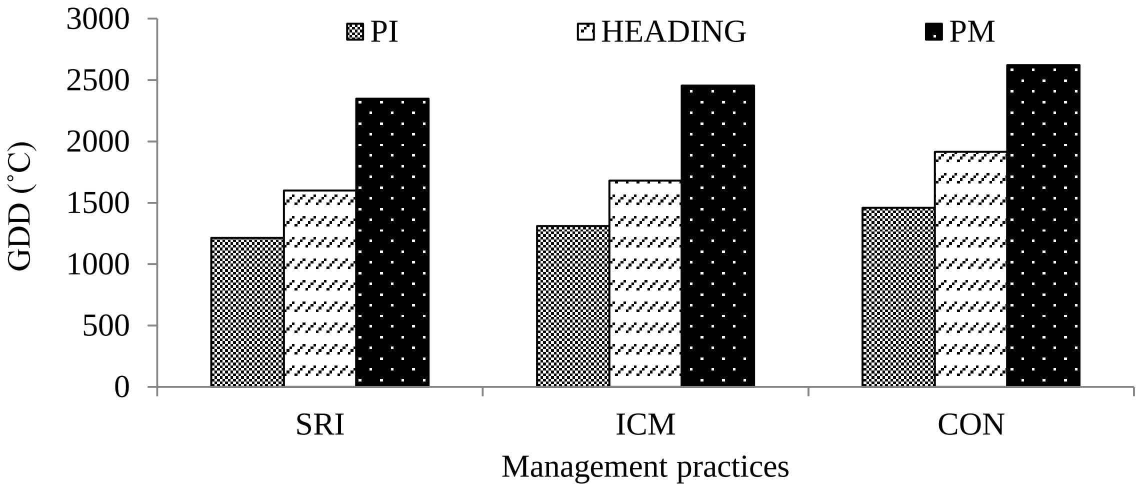


Figure 17. Comparison of GDD requirement of different phenological stages by different management practices of rice

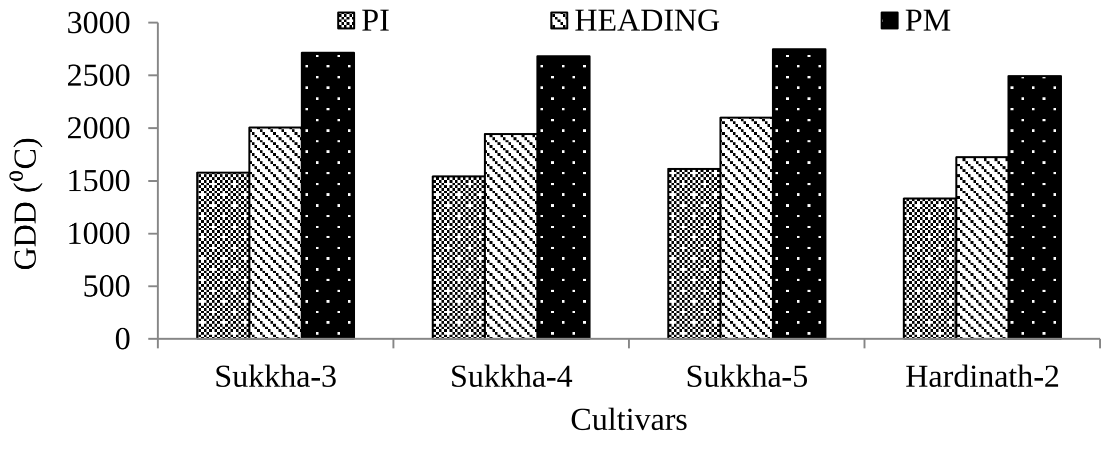


Figure 18. Comparison of GDD requirement of different phenological stages by different varieties of rice

**4.1.6.5 Heat use efficiency (HUE)**

The management practices had significant influence on heat use efficiency, but no significant influence of cultivars and the interactions of cultivars and management practices on heat use efficiency were recorded.

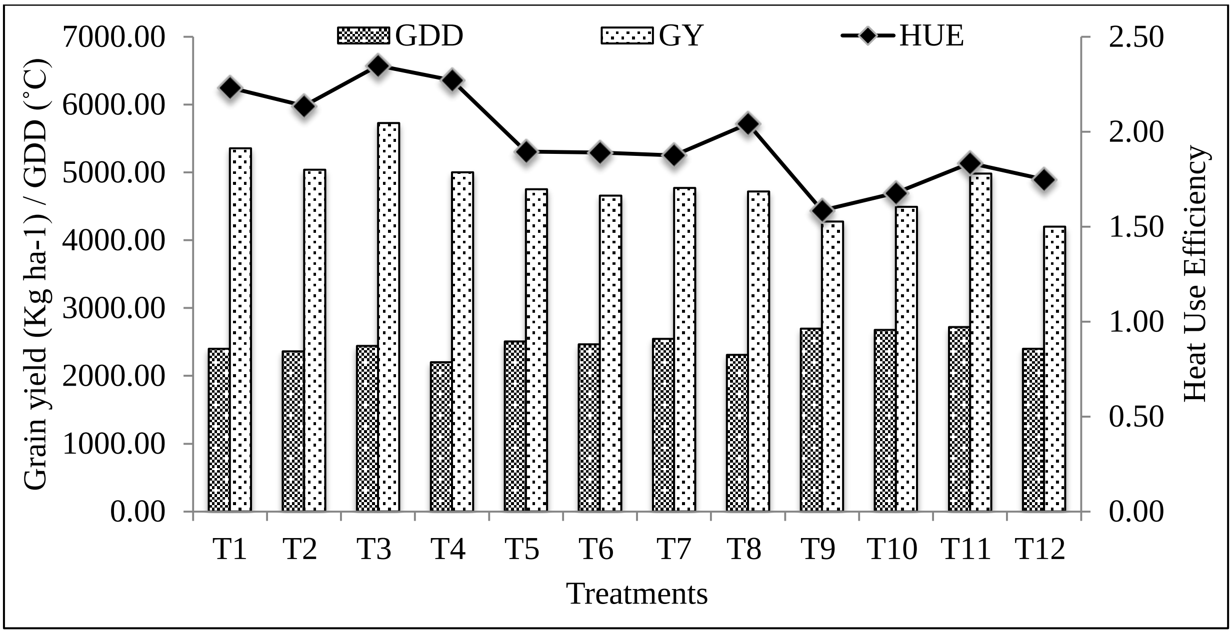


Figure 19. Comparison of grain yield, GDD and HUE of different treatments

The HUE of SRI practice (2.25) was significantly higher than ICM (1.93) and conventional (1.71) practices (Table 12). Sukkha-5 (2.02) and Hardinath-2 (2.02) had the greater HUE then other cultivars whereas Sukkha-5 with SRI management practice (2.23) had the greatest and Sukkha-3 with conventional practice (1.59) had the least HUE than other interactions.

**4.1.7 Economic Analysis**

**4.1.7.1 Cost of cultivation**

The data on cost of cultivation is presented in Table 13. The data on cost of cultivation revealed that SRI practice had the lowest cost of production (NRs. 88,005.68), followed by ICM (NRs. 95207.6) and conventional (NRs. 111909.12) practices, respectively. The mean cost of cultivation was NRS. 98374 $ha^{-1}$.

Table 13. Cost of cultivation (NRs. 000 $ha^{-1}$), gross return (NRs. 000 $ha^{-1}$), net return (NRs. 000 $ha^{-1}$) and B:C ratio of various cultivars of rice as affected by management practices at Dhauwadi VDC, Nawalparasi, Nepal, 2014

| Treatment | Cost of production (NRs. 000 $ha^{-1}$) | Gross return (NRs. 000 $ha^{-1}$) | Net return (NRs. 000 $ha^{-1}$) | B:C ratio |
|---|---|---|---|---|
| Management | | | | |
| SRI | 88.01 | 144.65 $^{a}$ | 56.65 $^{a}$ | 1.64 $^{a}$ |
| ICM | 95.21 | 129.94 $^{b}$ | 34.73 $^{b}$ | 1.37 $^{b}$ |
| CON | 111.91 | 121.93 $^{b}$ | 10.02 $^{c}$ | 1.09 $^{c}$ |
| SEm (±) | | 3.387 | 3.387 | 0.036 |
| LSD (0.05) | | 13.30 | 13.30 | 0.14 |
| Cultivars | | | | |
| Sukkha-3 | 98.37 | 133.30 | 34.95 | 1.38 |
| Sukkha-4 | 98.37 | 129.03 | 30.65 | 1.33 |
| Sukkha-5 | 98.37 | 139.55 | 41.18 | 1.44 |
| Hardinath-2 | 98.37 | 126.82 | 28.45 | 1.31 |
| SEm (±) | | 5.730 | 5.730 | 0.061 |
| LSD(0.05) | | ns | ns | ns |
| CV (%) | | 9.39 | 34.28 | 9.51 |
| Grand Mean | 98.37 | 132.18 | 36.20 | 1.365 |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

### 4.1.7.2 Gross return

The total monetary value of the economic produce and the byproducts obtained from the crop is called gross return. It is calculated based on the local market price of the products (Reddy and Reddi, 2005). The gross return was significantly influenced by management practices, but the cultivars and interactions of cultivars and management practices had no influence in gross return (Table 13). The gross return of SRI practice (NRs. 144652) was significantly higher than ICM (NRs. 129941) and conventional (NRs. 121931) practices. Higher gross return in SRI practice has also been reported by (Islam *et al.*, 2014b).

#### 4.1.7.3 Net return

The ultimate product remained after subtracting the cost of cultivation from the gross return is called net return (Reddy and Reddi, 2005). The net return was significantly influenced by management practices, but the cultivars and interactions of cultivars and management practices had no influence in net return. The net return of SRI practice (NRs. 56647) was significantly higher than ICM (NRs. 34733) and conventional (NRs. 10022) practices (Table 13). Higher net return in SRI practice has also been reported by (Islam *et al.*, 2014b).

#### 4.1.7.4 Benefit cost (B: C) ratio

Benefit cost (B: C) ratio is defined as the ratio of the gross returns to the cost of cultivation which can also be expressed as return per rupee invested. For any enterprise relating with agriculture sector to be economically viable, a minimum B: C ratio of 1.5 is fixed. Therefore for any agriculture enterprise to be sustainable, it should maintain a B: C ratio of 1.5 (Reddy and Reddi, 2005). The benefit cost ratio was significantly influenced by management practices, but the cultivars and interactions of cultivars and management practices had no influence in benefit cost ratio. The benefit cost ratio of SRI practice (1.64:1) was significantly higher than ICM (1.37:1) and conventional (NRs. 10022) practices (Table 13). Higher benefit cost ratio in SRI practice has also been reported by Wijebandara *et al.* (2008) and Islam *et al.* (2014b).

### 4.2 CSM-CERES-Rice model

Model calibration, model validation, and sensitivity analysis (determination of genetic coefficient) by using the CSM-CERES-DSSAT Ver. 4.5 crop model at Dhauwadi, Nawalparasi has been presented and expressed in Table (14, 15, 16 17), Figure (20, 21, 22, 230 and Appendix (13, 14, 15, 16, 20, 21, 22, 23, 24) The various steps are grouped into: model calibration, validation, and sensitivity analysis.

### 4.2.1 Model calibration

Determination of genetic coefficients of four rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) was estimated from several runs of model and presented in Appendix 13, 14, 15 and 16. The data sets for the four rice cultivars Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 with SRI management practices were used to determine the genetic coefficient of the rice cultivars under study by using the CSM-CERES-Rice and the following cultivar coefficients of rice has been calculated by hit and trial method.

P1 : Basic vegetative phase of the plant.

P20 : Critical photoperiod or the longest day length (in hours) at which the development occurs at a maximum rate

P2R : Extent to which phasic development leading to panicle initiation is delayed

P5 : Time period in GDD ($^0$C) from beginning of grain filling

G1 : Potential spikelet number coefficient

G2 : Single grain weight (g) under ideal growing conditions.

G3 : Tillering coefficient

G4 : Temperature tolerance coefficient.

For the estimation of genetic coefficients for all four rice cultivars, coefficient of IB0101, IB0102, IB0103 and IB0104 were used for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively. These genetic coefficients were then used for validation of the model.

The genetic coefficients for all four rice cultivars were adjusted until there was a match between the observed and simulated dates of anthesis, physiological maturity and grain yield. The details of the runs for calibrating anthesis, physiological maturity and grain yield of all four rice cultivars are presented in appendices (Appendix 13, 14, 15 and 16, respectively). The genetic coefficients for all four rice cultivars are presented in Table 14.

After running the model for more than 10 times with different possible changes in the values for genetic coefficients, anthesis, physiological maturity dates and grain yield were calibrated. The calibration results showed that anthesis dates and physiological maturity dates for Sukkha-3, Sukkha-4 and Sukkha-5 cultivars were perfectly equal to the observed data and grain yields were nearly equal to the observed data. However, anthesis date and physiological maturity date for Hardinath-2 was nearly equal to observed data.

Table 14: Genetic coefficients of different rice cultivars

| Rice | Genetic coefficients | | | | | | | | Simulated values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| cultivars | P1 | P2R | P5 | P2O | G1 | G2 | G3 | G4 | A* | P* | G*** |
| Sukkha-3 | 470 | 160 | 470 | 12 | 96 | 0.050 | 1.09 | 1.0 | 64 | 96 | 5357 |
| Sukkha-4 | 410 | 160 | 500 | 12 | 97 | 0.028 | 1.09 | 1.0 | 61 | 94 | 5045 |
| Sukkha-5 | 560 | 160 | 440 | 12 | 94 | 0.040 | 0.98 | 1.0 | 68 | 98 | 5735 |
| Hardinath-2 | 200 | 180 | 540 | 11.8 | 96 | 0.070 | 0.80 | 1.03 | 56 | 92 | 4726 |

Note- A* = 75% Anthesis day, P**= 75% Physiological maturity day G*** = Grain yield (kg $ha^{-1}$)

### 4.2.2 Validation of the model

The CERES-Rice model was tested and validated by using the above determined genetic coefficients of all tested four varieties (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) with their respective crop management practices (ICM and conventional management practices). Observation on anthesis and physiological maturity dates, grain yield and tops weight at maturity were used for the model validation. Predicted physiological maturity date was well agreed with observed physiological maturity date (RMSE=2.55, d-stat =0.925 and $R^2$=0.839) (Figure 21). Similarly, close agreement was observed between observed and simulated anthesis date (RMSE=2.525, d-stat =0.956 and $R^2$=0.895) (Figure 20).

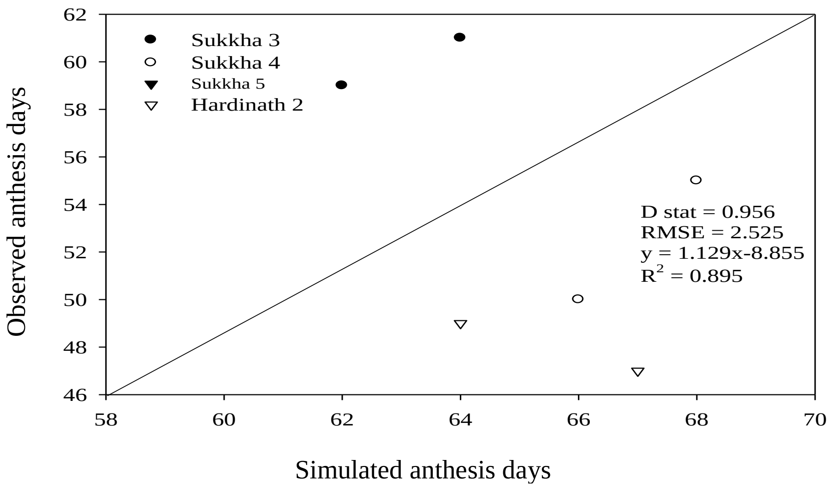


Figure 20. Simulated and observed anthesis days for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2

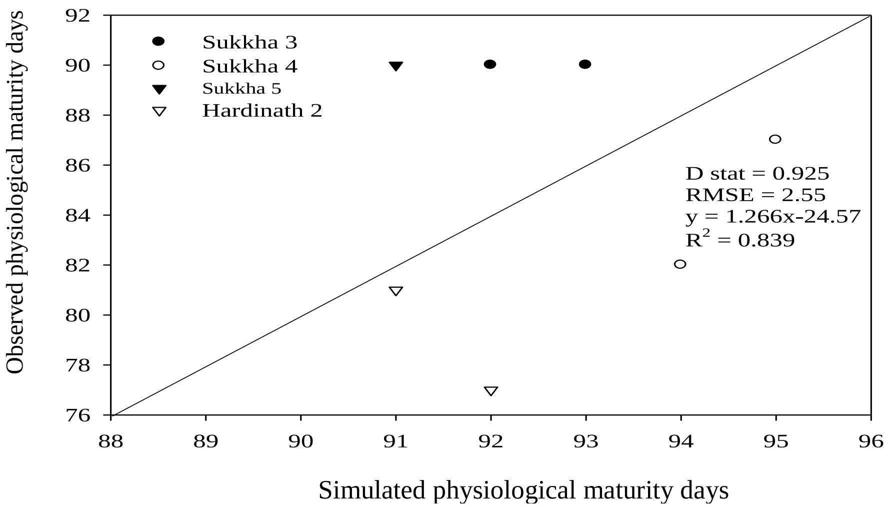


Figure 21. Simulated and observed physiological maturity days for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2

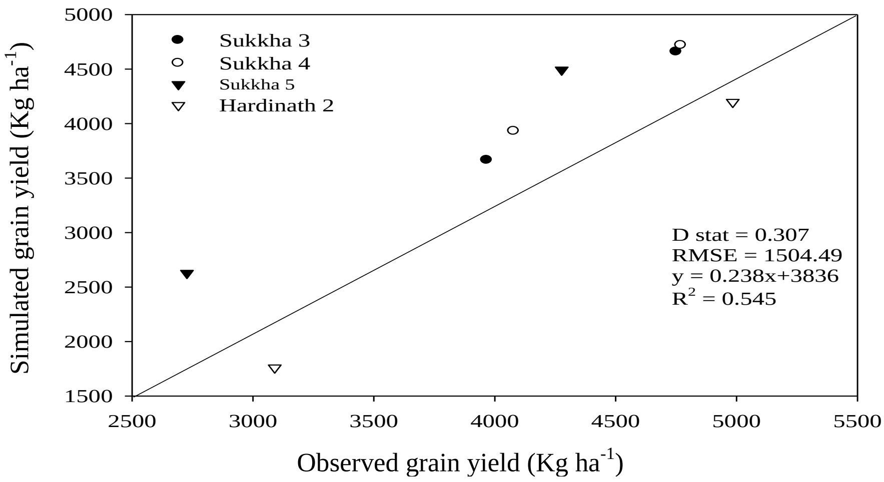


Figure 22. Simulated and observed grain yield for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2

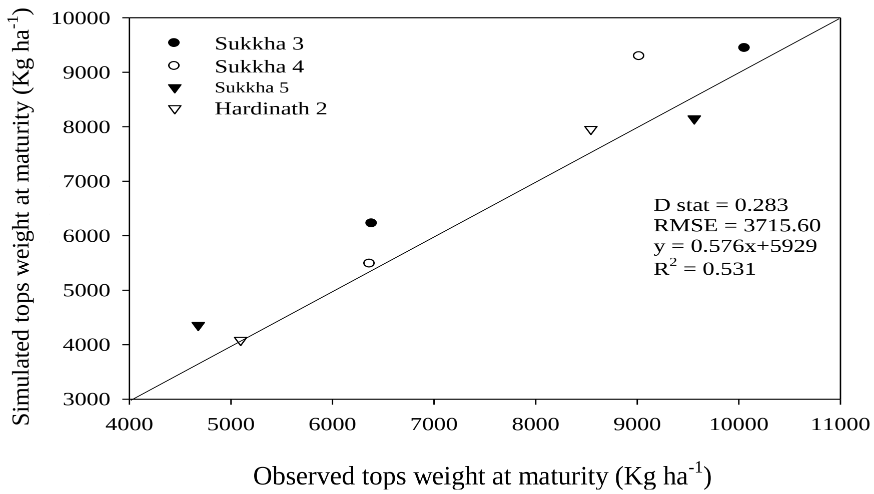


Figure 23. Simulated and observed tops weight at maturity for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2

The agreement between observed and simulated grain yield (RMSE=1504.495, d-stat =0.307 and $R^2$=0.545) (Figure 22), and tops weight at maturity (RMSE=3715.596, d-stat =0.283 and $R^2$=0.531) (Figure 23) was also observed at model validation. These validation results showed that the CERES-Rice model could be safely used as a tool for simulation of different agronomic and climate change parameters to the sub-humid sub-tropical weather condition of central-western terai and can be extrapolated the simulation work in similar agroclimatic condition.

### 4.3 Sensitivity analysis

#### 4.3.1 Sensitivity to weather years

CERES-Rice was run for the standard treatment using 7 years of weather data (2008-2014) of research site of Nawalparasi. The simulated yields were sensitive to various weather years. It was revealed that the highest yield declining year was 2012 for all rice cultivars. There was 8.34% yield declined in Sukkha-3 in the year of 2012, whereas the yield decline for Sukkha-4, Sukkha-5 and Hardinath-2, in the year 2012 was 6.63%, 28% and 8.04%, respectively (Table 15). This decline in the yield might be due to the less rainfall in the year 2012 as compare to the 2014. Low rainfall creates water related stresses and reduces the yield (IRRI, 2002; Sarvestani *et al.*, 2008).

Results further depicted that average daily solar radiation was quite low and low rainfall over rice growing season in 2010 resulting in declining the yield of Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 by 6.43%, 4.23%, 23.72% and 7.84%, respectively. It was revealed that average temperature and rainfall was lower in the year of 2008, which declined the yield by 3.68%, 2.29%, 22.88% and 5.32% in Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively. Sukkha-5 was affected more than other cultivars. The physiological maturity days was increased for all the weather years when compared over standard year, which might be due to low daily average temperature for all the weather years than standard year.

Table 15. Sensitivity of simulated yield and phenology of rice cultivars to weather years

| | Weather years | Simulated yield (kg ha$^{-1}$) | Percent yield | Anthesis (days) | Physiological maturity (days) |
|---|---|---|---|---|---|
| Sukkha-3 | 2014[a] | 3967 | 100.00 | 64 | 93 |
| | 2012 | 3636 | 91.66 | 70 | 102 |
| | 2010 | 3712 | 93.57 | 71 | 104 |
| | 2008 | 3821 | 96.32 | 72 | 106 |
| Sukkha-4 | 2014[a] | 3665 | 100.00 | 61 | 90 |
| | 2012 | 3422 | 93.37 | 66 | 100 |
| | 2010 | 3510 | 95.77 | 67 | 102 |
| | 2008 | 3581 | 97.71 | 68 | 104 |
| Sukkha-5 | 2014[a] | 3090 | 100.00 | 64 | 91 |
| | 2012 | 2225 | 72.00 | 69 | 100 |
| | 2010 | 2357 | 76.28 | 71 | 102 |
| | 2008 | 2383 | 77.12 | 73 | 106 |
| Hardinath-2 | 2014[a] | 3931 | 100.00 | 55 | 87 |
| | 2012 | 3615 | 91.96 | 59 | 94 |
| | 2010 | 3623 | 92.16 | 60 | 96 |
| | 2008 | 3722 | 94.68 | 61 | 98 |

Note: [a] Standard years

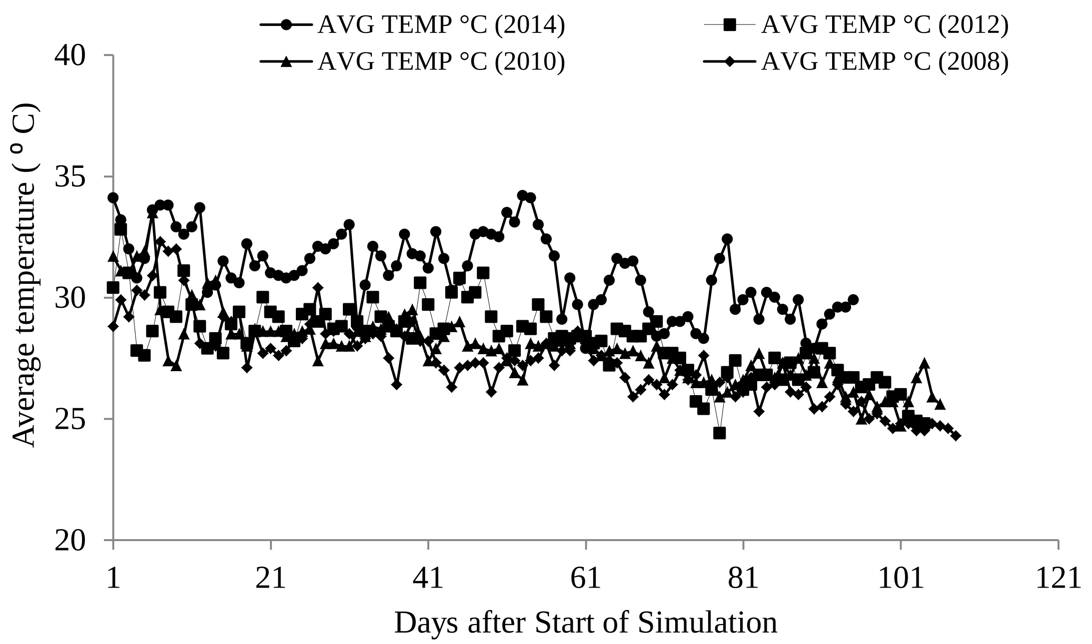


Figure 24. Daily average temperature ($^{0}$C) during rice season

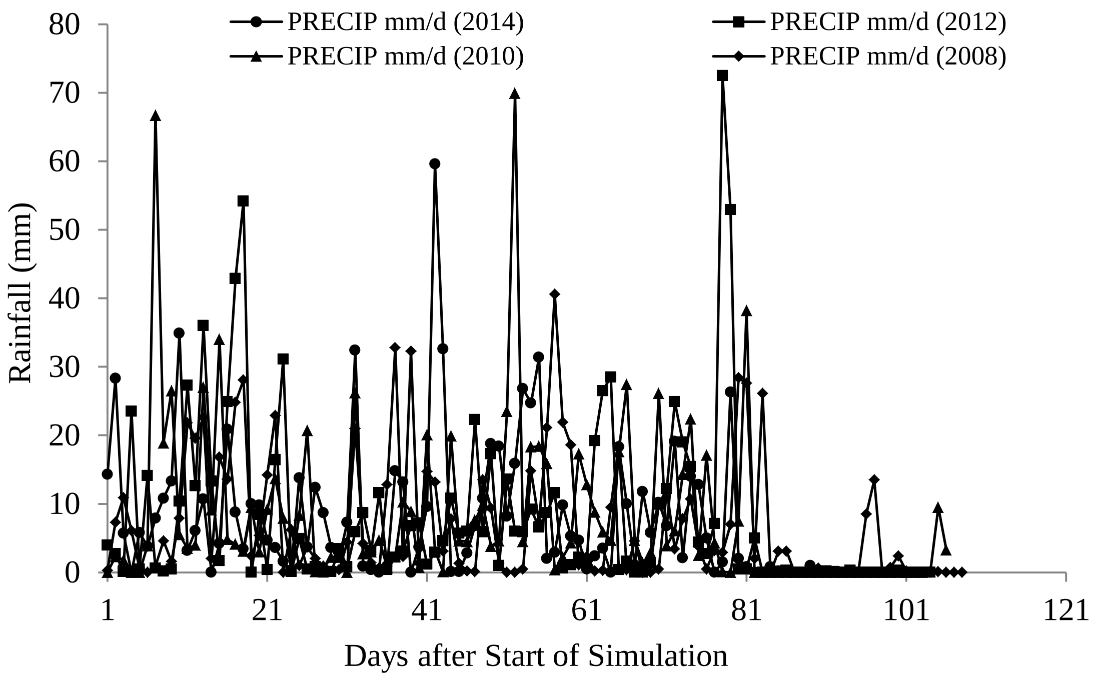


Figure 25. Daily rainfall (mm) during rice season

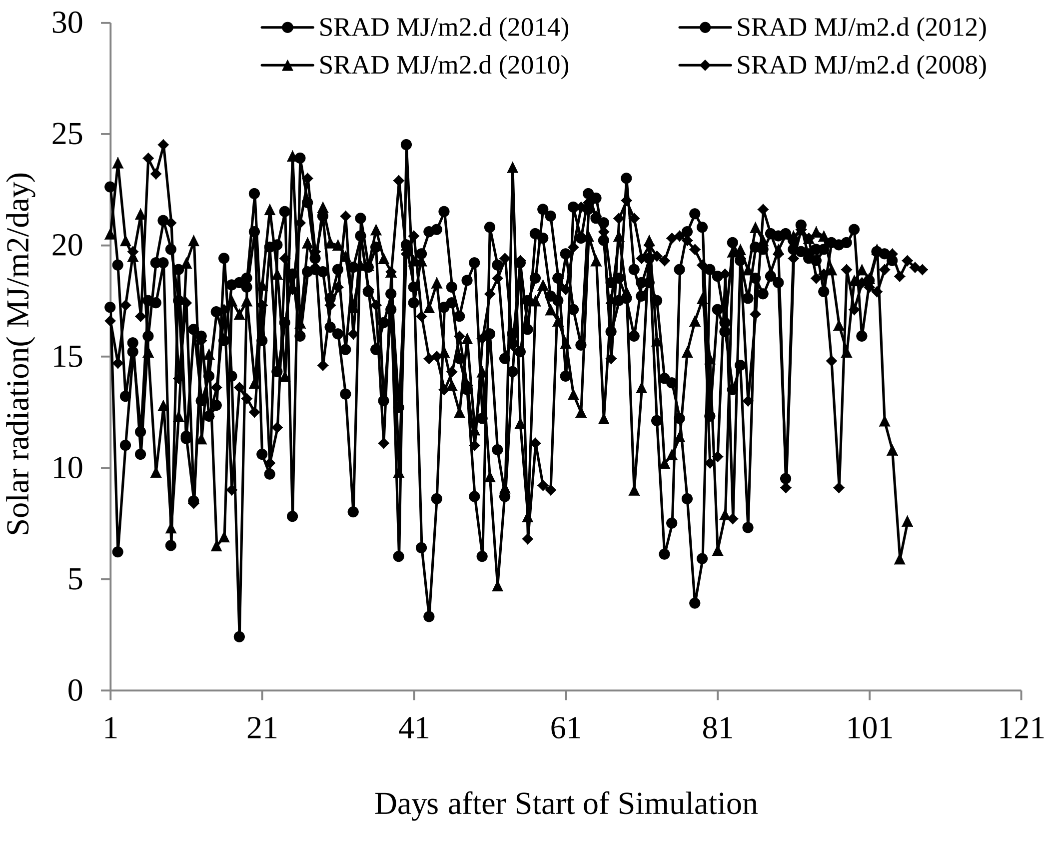


Figure 26. Daily Solar radiation (MJ/m$^2$/day) during rice season

### 4.3.2 Sensitivity to transplanting date

Model response to the transplanting dates for each rice cultivars was found to be perfect. For Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, there were 22.01%, 22.26% 63.11% and 53.22% yield decline, respectively when one month delay (4$^{th}$ August) of transplanting. The grain yield was increased by 2.48% and 5.44% in one month early transplanting (4$^{th}$ June) for Sukkha-4 and Sukkha-5, respectively, but the grain yield was decreased by 22.54% and 10.51% in Sukkha-3 and Hardinath-2, respectively, as compared to 4$^{th}$ July transplanting.

Table 16**.** Sensitivity of simulated yield and phenology of rice cultivars to date of planting.

| | Transplanting dates | Simulated yield (kg ha$^{-1}$) | Percent yield | Anthesis (days) | Physiological maturity (days) |
|---|---|---|---|---|---|
| Sukkha-3 | 4$^{th}$ Jul [a] | 3967 | 100.00 | 64 | 93 |
| | 4$^{th}$ Jun | 3073 | 77.46 | 90 | 118 |
| | 4$^{th}$ Aug | 3094 | 77.99 | 60 | 93 |
| Sukkha-4 | 4$^{th}$ Jul [a] | 3665 | 100.00 | 61 | 90 |
| | 4$^{th}$ Jun | 3756 | 102.48 | 73 | 103 |
| | 4$^{th}$ Aug | 2849 | 77.74 | 56 | 91 |
| Sukkha-5 | 4$^{th}$ Jul [a] | 3090 | 100.00 | 64 | 91 |
| | 4$^{th}$ Jun | 3258 | 105.44 | 75 | 101 |
| | 4$^{th}$ Aug | 1440 | 36.89 | 60 | 91 |
| Hardinath-2 | 4$^{th}$ Jul [a] | 3931 | 100.00 | 55 | 87 |
| | 4$^{th}$ Jun | 3518 | 89.49 | 69 | 100 |
| | 4$^{th}$ Aug | 1839 | 46.78 | 51 | 86 |

Note: [a] Standard date of transplanting

Higher grain yield in standard transplanting date (4$^{th}$ July) might be due to optimum availability of solar radiation and favorable temperature for growth and development of rice during this growing period. The monsoon period of Nepal (June-September) also falls during this period. Thus, the crop encounters less water stress.

With one month late transplanting, the temperature cools down at the flowering time. Thus, the flowering will be delayed until GDD requirement is fulfilled. Further, sunshine hours also reduce, causing reduction in daylength, which causes negative impact in growth during vegetative phase. Moreover, August planting will have less monsoon period, leading the crop to encounter more water stress. All these factors subsequently reduces the yield in one month late transplanting (4$^{th}$ August). However, in one early transplanting, rice encounters water stress at the early vegetative stage. As a result, yield reduces in one month early transplanting (4$^{th}$ June).

### 4.3.3 Sensitivity to Climate Change

Various scenarios of temperature, carbon dioxide concentration and solar radiation were selected for running sensitivity analysis of yields simulated by CERES-Rice for each cultivar (Table 17). Compared to simulated yield of standard treatment, the increase in yield was 1.87% for Sukkha-3 whereas the yield was nearly same for Sukkha-4, Sukkha-5 and Hardinath-2 with the decrease in both maximum and minimum temperature by 4$^{o}$C, but, increase in both maximum and minimum temperature by 4$^{o}$C decreased the yield by 16.56%, 48.68%, 21.68% and 73.04% for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively. Elevated $CO_2$ by 20 ppm along with increased temperature had resulted in decrease in grain yield by 11.95%, 48.05%, 20.94% and 72.15%, respectively for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2. But, in combination with decreased temperature and elevated $CO_2$, there was increase in yield by 1.74%, 0.13% and 0.71%, respectively for Sukkha-3, Sukkha-5 and Hardinath-2; whereas the yield was nearly same for Sukkha-4. Simulated grain yield was found to be decreased by 5.02%, 45.16%, 5.79% and 67.24%, respectively for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 when there was increased in 1 MJ $m^{-2}day^{-1}$ solar radiation along with the increased temperature (by $4^oC$) and $CO_2$ concentration (by 20 ppm).

Decrease in yield by 20.07%, 51.22%, 22.07% and 75.25% for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively with the decrease in solar radiation by 1 MJ $m^{-2}$ $day^{-1}$ along with increase in temperature (by $4^oC$) and $CO_2$ concentration (by 20 ppm). Under decreased temperature (by $4^oC$), increased $CO_2$ concentration (by 20 ppm) and increase in solar radiation amount by 1 MJ $m^{-2}$ $day^{-1}$, grain yield was increased by 3.86%, 1.45%, 0.26% and 1.68% for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively. Decrease in solar radiation amount by 1 MJ $m^{-2}$ $day^{-1}$, decreased temperature (by $4^oC$) and increased $CO_2$ concentration (by 20 ppm), the yield was increased by 0.10% and 0.58% for Sukkha-3 and Sukkha-5, respectively, whereas the yield decreased by 1.64% and 1.96% for Sukkha-4 and Hardinath-2, respectively.

Under increased temperature condition (along with elevated $CO_2$ and increased or decreased solar radiation), the growth duration of rice cultivars was found decreased and consequently decreased in yield. Likewise, it was found to be increased in crop duration and yield for decreased in maximum and minimum temperature by $4^oC$ (Table 17). Temperature primarily affected growth duration with lower temperature increasing the length of time that the crop could intercept radiation.

Table 17: Sensitivity analysis of rice cultivars with changes in temperature, solar radiation and $CO_2$ concentration

| Max temp (°C) | Min temp (°C) | $CO_2$ conc. (ppm) | Solar radiation (MJ $m^{-2}$ $day^{-1}$) | Cultivars | Simulated yield (kg $ha^{-1}$) | Percent yield | Growth duration (days) |
|---|---|---|---|---|---|---|---|
| +0[a] | +0 | 398 | +0 | Sukkha-3 | 3967 | 100 | 93 |
| | | | | Sukkha-4 | 3665 | 100 | 90 |
| | | | | Sukkha-5 | 3090 | 100 | 91 |
| | | | | Hardinath-2 | 3931 | 100 | 87 |
| +4 | +4 | 398 | +0 | Sukkha-3 | 3310 | 83.44 | 86 |
| | | | | Sukkha-4 | 1881 | 51.32 | 84 |
| | | | | Sukkha-5 | 2420 | 78.32 | 87 |
| | | | | Hardinath-2 | 1060 | 26.96 | 82 |
| -4 | -4 | 398 | +0 | Sukkha-3 | 4041 | 101.87 | 111 |
| | | | | Sukkha-4 | 3648 | 99.54 | 108 |
| | | | | Sukkha-5 | 3079 | 99.64 | 111 |
| | | | | Hardinath-2 | 3930 | 99.97 | 100 |
| +4 | +4 | +20 | +0 | Sukkha-3 | 3493 | 88.05 | 87 |
| | | | | Sukkha-4 | 1904 | 51.95 | 84 |
| | | | | Sukkha-5 | 2443 | 79.06 | 87 |
| | | | | Hardinath-2 | 1095 | 27.85 | 82 |
| -4 | -4 | +20 | +0 | Sukkha-3 | 4036 | 101.74 | 111 |
| | | | | Sukkha-4 | 3662 | 99.92 | 108 |
| | | | | Sukkha-5 | 3094 | 100.13 | 111 |
| | | | | Hardinath-2 | 3959 | 100.71 | 100 |
| +4 | +4 | +20 | +1 | Sukkha-3 | 3768 | 94.98 | 88 |
| | | | | Sukkha-4 | 2010 | 54.84 | 84 |
| | | | | Sukkha-5 | 2911 | 94.21 | 87 |
| | | | | Hardinath-2 | 1288 | 32.76 | 83 |
| +4 | +4 | +20 | -1 | Sukkha-3 | 3171 | 79.93 | 86 |
| | | | | Sukkha-4 | 1788 | 48.78 | 84 |
| | | | | Sukkha-5 | 2408 | 77.93 | 87 |
| | | | | Hardinath-2 | 973 | 24.75 | 82 |
| -4 | -4 | +20 | +1 | Sukkha-3 | 4120 | 103.86 | 111 |
| | | | | Sukkha-4 | 3718 | 101.45 | 108 |
| | | | | Sukkha-5 | 3098 | 100.26 | 111 |
| | | | | Hardinath-2 | 3997 | 101.68 | 100 |
| -4 | -4 | +20 | -1 | Sukkha-3 | 3971 | 100.10 | 111 |
| | | | | Sukkha-4 | 3605 | 98.36 | 108 |
| | | | | Sukkha-5 | 3108 | 100.58 | 111 |
| | | | | Hardinath-2 | 3854 | 98.04 | 100 |

Note: [a] Standard climatic conditions

# 5 SUMMARY AND CONCLUSIONS

## 5.1 Summary

A fieldexperimentation was carried out in rainy season of 2014 at the farmers' field of Nawalparasi district to evaluate the best management practices over different drought tolerant rice cultivars. CSM-CERES-Rice ver. 4.5 was also evaluated simultaneously for its ability to simulate the agronomic and climate change parameter of drought tolerant cultivars of rice under different crop management practices. The experiment was conducted in strip plot design in three farmers' field. Soil of experimental field was loam in texture, whereas initial content of N was medium in surface horizon and lower in sub surface horizon, whereas soil available P and K was high in surface horizon and medium in sub surface horizon. There were altogether twelve treatments comprising four rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2) and three crop management practices (SRI, ICM and conventional).

The study revealed that cultivars had non-significant effect on grain yield and yield attributes of rice except panicle length and weight. However, management practices had significant effect on grain yield and yield attributes of rice. Significantly higher yield was recorded in SRI (5.28 t $ha^{-1}$) than conventional (4.49t $ha^{-1}$), but was at par with ICM (4.73t $ha^{-1}$).It was revealed that SRI practice produced 17.49% more yield than conventional practice. Although SRI and ICM practices were statistical similar, SRI produced 11.63% more yield than ICM practice. Moreover, ICM also produced 5.35 % more grain yield as compared to conventional management practice.Yield attributes like effective tillers $m^{-2}$was observed significantly higher from SRI (317.7) than conventional (227.7), but at par with ICM (287.1). The panicle weight of Sukkha-5 (4.19 g) was at par with Sukkha-3 (3.91 g), Sukkha-4 (3.89 g) and significantly higher than Hardinath-2 (3.34 g). Significantly longer panicle length was found in Sukkha-5 (26.90 cm) than Sukkha-4 (24.98 cm) and

Hardinath-2 (24.95 cm), but at par with Sukkha-3 (26.13). SRI management practice had significantly higher panicle length (26.46 cm) than ICM (25.93 cm) and conventional (24.83 cm). Panicle weight was significantly higher in SRI (4.34 g) than conventional (3.34 g), but was at par with ICM (3.82 g). Significantly higher number of filled grains per panicle was recorded under SRI (167.0) than ICM (143.8) and conventional (128.3) practices. Significantly higher sterility percentage was recorded in conventional (16.23) than ICM (15.13) and SRI (14.97). The cultivars do not have influence on effective tillers number, test weight, sterility percentage, filled grains per panicle, per panicle length and per panicle weight whereas management practices have no influence in test weight. The interaction of cultivars and management practices has no influence on yield and yield attributes except sterility percentage.

Results showed that cultivars had no influence on yield and harvest index, but had significant influence on straw yield. Sukkha-3 had significantly higher straw yield (5.21 t $ha^{-1}$) than Sukkha-5 (4.49 t $ha^{1}$), Sukkha-4 (4.43 t $ha^{1}$) and Hardinath-2 (4.42 t $ha^{1}$). Management practices had no influence in harvest index, but had significant influence in grain yield and straw yield. The significantly higher straw yield was found in SRI (5.12 t $ha^{1}$) than ICM (4.73 t $ha^{1}$) and conventional (4.06 t $ha^{1}$) practices.

There was non-significant interaction effect of management practices and cultivars in grain yield, but had significant influence in straw yield and harvest index. The mean straw yield was found the highest in Sukkha-5 cultivar with SRI (5.66 t $ha^{-1}$), followed by Sukkha-3 with ICM practices (5.31 t $ha^{-1}$). The lowest mean straw yield was observed in Sukkha-5 cultivar with conventional practice (3.56 t $ha^{-1}$). Similarly,the highest mean harvest index (54.75%) was observed in Sukkha-5 with conventional practice, followed by Sukkha-4 with conventional practice (51.33%). The lowest mean harvest index (41.03%) was found in Sukkha-3 with conventional practice.

Dry matter accumulation (kg ha$^{-1}$) at harvest was not significant in case of Sukkha-3 (9336), Sukkha-4 (8500), Sukkha-5 (8928) and Hardinath-2 (8409). In case of management practices, SRI recorded significantly higher dry matter accumulation (9664 kg ha$^{-1}$) than other management practices. There was positive correlation between dry matter accumulation and grain yield (r=0.72). Higher LAI was resulted on cultivars Sukkha-3 (4.571) and Sukkha-5 (3.976). Under SRI management practice, higher leaf area index (4.257) was recorded. There was positive correlation between LAI and grain yield (r =0.46). Interaction between cultivars and management practices showed the significant effect on growth attributes as dry matter accumulation and leaf area index (LAI). Tillers number m$^{-2}$ was not influenced by cultivars and management practices. Cultivars and management practices interaction showed non-significant effect on tillers number m$^{-2}$.

Sukkha-5 required the maximum days to reach panicle initiation (61 DAS), heading (83 DAS) and physiological maturity (115.67 DAS). Similarly, conventional practice required the maximum days to reach panicle initiation (60.50 DAS), heading (81.25 DAS) and physiological maturity (115.50 DAS). Sukkha-5 required the maximum GDD to reach panicle initiation (1431.32°C), heading (1909.20°C) and physiological maturity (2567.36°C). Similarly, conventional practice required the maximum GDD to reach panicle initiation (1459.44°C), heading (1915.24°C) and physiological maturity (2622.83°C). The HUE was significantly higher in SRI practice (2.25) than ICM (1.93) and conventional (1.71) practices. The minimum cost of cultivation (NRs. 88,005.68ha$^{-1}$) and the highest gross return (NRs.144652ha$^{-1}$), net return (NRs. 56647ha$^{-1}$) and B:C ratio (1.64:1) was recorded in SRI practice.

For evaluation of CSM-CERES-Rice model, DSSAT ver. 4.5 was used at Dhauwadi, Nawalparasi condition. Model calibration was done for four rice cultivars (Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2)withSRI crop management practice.

Parameters like observed anthesis days, physiological maturity days and grain yield were used for determining the genetic coefficients. The genetic coefficients were adjusted until there was a match between the observed and simulated dates of anthesis, physiological maturity and to the grain yield. The determined genetic coefficients for Sukkha-3 were: 470 (P1), 160 (P2R), 470 (P5), 12 (P2O), 96 (G1), 0.050 (G2), 1.09(G3) and 1.0 (G4). For Sukkha-4, the same values were: 410 (P1), 160(P2R), 500 (P5), 12 (P2O), 97(G1), 0.028 (G2), 1.09 (G3) and 1.0 (G4). Genetic coefficient for Sukkha-5 were 560 (P1), 160 (P2R), 440 (P5), 12 (P2O), 94 (G1), 0.040 (G2), 0.98 (G3) and 1.0 (G4). Similarly, genetic coefficient for Hardinath-2 were 200 (P1), 180 (P2R), 540 (P5), 11.8 (P2O), 96 (G1), 0.070 (G2), 0.8 (G3) and 1.03 (G4). For the estimation of genetic coefficient, coefficient of IB0101, IB0102, IB0103 and IB0104 were used for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2, respectively.

The CERES-Rice model was tested and validated by using the above determined genetic coefficients of four cultivars with their respective management practices except to those which was used for model calibration. Observation result on days to anthesis(RMSE=2.525, d-stat =0.956 and $R^2$=0.895)and physiological maturity dates (RMSE=2.55, d-stat =0.925 and $R^2$=0.839), grain yield (RMSE=1504.495, d-stat =0.307 and $R^2$=0.545) and tops weight at maturity (RMSE=3715.596, d-stat =0.283 and $R^2$=0.531) were found to be perfectly matchable. Those RMSE and d-stat and $R^2$ values showed that the CERES-Rice model can be safely used as a tool for sensitivity analysis under sub-tropical condition of Nawalparasi and similar agroclimatic zones.

By running sensitivity analysis, the model was found sensitive to weather years, transplanting date and various parameters of climate change. The simulated yield for Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2 was reduced by8.34%, 6.63%, 28% and

8.04%, respectively in 2012. In the year 2008, Sukkha-5 produced 22.88% lesser yield than standard.

Similarly,there was well response of model to the transplanting dates for each rice cultivars. For Sukkha-3, Sukkha-4,Sukkha-5 and Hardinath-2, there were 22.01%, 22.26% 63.11% and 53.22%yield decline, respectively when one month delay ($4^{th}$ August) of transplanting. The grain yield was increased by 2.48% and 5.44% in one month early transplanting ($4^{th}$ June) for Sukkha-4 and Sukkha-5, respectively, but the grain yield was decreased by 22.54% and 10.51% in Sukkha-3 and Hardinath-2,respectively, as compared to $4^{th}$ July transplanting.

The model was also sensitive to climate change parameter (temperature, solar radiation and $CO_2$ concentration).Change in temperature (- $4^0$C ), $CO_2$ concentration (+20 ppm) with change in solar radiation (+1MJ $m^{-2}$ $day^{-1}$) resulted maximum increase in yield of Sukkha-3, Sukkha-4and Hardinath-2 by 3.86%, 1.45% and 1.68%, respectively, while the maximum increase in yield for Sukkha-5 was 0.58% with change in temperature (- $4^0$C), $CO_2$ concentration (+20 ppm),and solar radiation (-1MJ $m^{-2}$ $day^{-1}$). The maximum decrease in yieldof Sukkha-3, Sukkha-4, Sukkha-5 and Hardinath-2was recorded by 20.07%, 51.22%, 22.07% and 75.25%, respectively when the change in temperature (+$4^0$C), $CO_2$ concentration (+20 ppm) and solar radiation (-1MJ $m^{-2}$ $day^{-1}$).

**5.2 Conclusions**

Drought is the most important limiting factor for crop production and it is becoming an increasingly severe problem in many regions of the world. According to statistics, the percentage of drought affected land areasin the world increased more than doubled from the 1970s to the early 2000s. It is a world-spread problem seriously influencing grain production and quality and with increasing population and global climate change making the situation more serious. To achieve the higher production of the rice in this water scarce environment, selection of appropriate crop management practice and cultivar is crucial. Drought tolerant cultivar Sukkha-5, grown under SRI management practice yields higher as compared to other cultivars and crop management practices under subtropical condition. CSM-CERES Rice Model is well validated in Nawalparasi condition and shows the immense scope of using CERES model as a tool for estimating potential yield and effect of different agronomic and climate change parameter under Nawalparasi condition.

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# APPENDICES

**Appendix 1.** Mean Square from ANOVA of grain yield, straw yield and harvest index as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Grain yield | Straw yield | Harvest Index |
|---|---|---|---|---|
| Replication | 2 | 0.205 | 0.433 | 15.77 |
| Management | 2 | 1.983* | 3.433** | 26.36 |
| Error (a) | 4 | 0.253 | 0.039 | 9.38 |
| Cultivar | 3 | 0.467 | 1.328** | 54.91 |
| Error (b) | 6 | 0.503 | 0.105 | 15.17 |
| Management x Cultivar | 6 | 0.128 | 0.832** | 31.79* |
| Error (c) | 12 | 0.273 | 0.056 | 10.13 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 2.** Mean Square from ANOVA of effective tillers, test weight, sterility percentage, filled grain per panicle, per panicle length and per panicle weight as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Effective tillers | Per panicle length | Per panicle weight | Filled grain per panicle | Sterility percentage | Test weight |
|---|---|---|---|---|---|---|---|
| Replication | 2 | 3786.59 | 4.166 | 0.846 | 414.70 | 2.797 | 24.97 |
| Management | 2 | 25129.72* | 8.292** | 3.016* | 4547.20** | 5.642 | 11.39 |
| Error (a) | 4 | 2349.79 | 0.053 | 0.240 | 186.54 | 0.770 | 12.28 |
| Cultivar | 3 | 8447.51 | 8.057** | 1.111* | 1673.46** | 1.356 | 7.46 |
| Error (b) | 6 | 3001.65 | 0.600 | 0.191 | 353.87 | 0.692 | 8.53 |
| Management x Cultivar | 6 | 1599.77 | 0.469 | 0.055 | 46.25 | 6.917 | 2.04 |
| Error (c) | 12 | 827.71 | 10160 | 0.213 | 311.27 | 0.781 | 4.86 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 3.** Mean Square from ANOVA of growing degree days and heat use efficiency as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Growing Degree Days | | | Heat Use Efficiency |
|---|---|---|---|---|---|
| | | Panicle Initiation | Heading | Physiological Maturity | |
| Replication | 2 | 511.89 | 8063.90 | 443.15 | 0.026 |
| Management | 2 | 181410.39** | 321816.07** | 227742.71** | 0.868* |
| Error (a) | 4 | 37.10 | 4437.64 | 33.19 | 0.041 |
| Cultivar | 3 | 146735.37** | 356885.14** | 125560.84** | 0.040 |
| Error (b) | 6 | 976.03 | 7920.59 | 1127.19 | 0.092 |
| Management x Cultivar | 6 | 2273.09** | 13694.57 | 2763.97** | 0.016 |
| Error (c) | 12 | 203.07 | 4857.54 | 37.25 | 0.045 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 4.** Mean Square from ANOVA of leaf area index at various growth stages and phenology as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Leaf Area Index | | | Phenology | | |
|---|---|---|---|---|---|---|---|
| | | 30 DAT | 45 DAT | 60 DAT | Panicle Initiation (DAS) | Heading (DAS) | Physiological Maturity (DAS) |
| Replication | 2 | 0.374** | 0.460* | 1.667* | 1.33 | 1.58 | 1.58** |
| Management | 2 | 3.323** | 6.869** | 1.380* | 185.25** | 363.25** | 196.00** |
| Error (a) | 4 | 0.017 | 0.032 | 0.128 | 0.21 | 0.08 | 0.08 |
| Cultivar | 3 | 0.211 | 0.661 | 1.647 | 314.92** | 463.33** | 305.67** |
| Error (b) | 6 | 0.049 | 0.152 | 0.416 | 2.33 | 2.69 | 2.92 |
| Management x Cultivar | 6 | 0.154** | 0.770** | 0.815** | 4.92** | 3.58** | 4.67** |
| Error (c) | 12 | 0.017 | 0.073 | 0.079 | 0.37 | 0.19 | 0.08 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 5.** Mean Square from ANOVA of tillers number as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Tiller number | | | | | |
|---|---|---|---|---|---|---|---|
| | | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At Harvest |
| Replication | 2 | 2883.93 | 436.75 | 262.49 | 1304.47 | 2407.31 | 3102.93 |
| Management | 2 | 143724.68** | 37405.44** | 22933.11** | 26507.86* | 18407.07 | 22949.19 |
| Error (a) | 4 | 950.12 | 376.01 | 284.29 | 2452.65 | 4245.38 | 4118.32 |
| Cultivar | 3 | 3375.84** | 17670.44** | 13920.63** | 12559.51 | 7685.23 | 10778.52 |
| Error (b) | 6 | 291.00 | 293.59 | 366.01 | 3623.67 | 4071.07 | 2976.38 |
| Management x Cultivar | 6 | 7183.01** | 2344.59* | 3822.34** | 3564.39 | 3178.56* | 2145.78 |
| Error (c) | 12 | 558.16 | 559.96 | 238.74 | 1191.33 | 796.48 | 1129.79 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 6.** Mean Square from ANOVA of dry matter accumulation at various growth stages as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Dry matter | | | | | |
|---|---|---|---|---|---|---|---|
| | | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At Harvest |
| Replication | 2 | 43455.27 | 401377.79 | 380559.87 | 39298.93 | 1152864.83 | 727360.50 |
| Management | 2 | 2963450.17** | 9361226.07** | 7478849.15* | 8836043.42** | 3933243.42** | 9092112.86** |
| Error (a) | 4 | 1943.47 | 19483.98 | 527058.78 | 327203.39 | 189848.99 | 134381.76 |
| Cultivar | 3 | 312201.42** | 2110428.27** | 4586161.72** | 1159192.50 | 1181146.40 | 1640036.49 |
| Error (b) | 6 | 9110.69 | 49871.35 | 94372.04 | 256456.75 | 410726.58 | 537203.15 |
| Management x Cultivar | 6 | 143707.32** | 10744527.49** | 5257045.65** | 6363287.02** | 1422079.80* | 876656.52* |
| Error (c) | 12 | 5221.98 | 42556.33 | 232321.89 | 137689.74 | 268181.77 | 221373.95 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 7.** Mean Square from ANOVA of plant height at various growth stages as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Plant height | | | | | |
|---|---|---|---|---|---|---|---|
| | | 30 DAT | 45 DAT | 60 DAT | 75 DAT | 90 DAT | At Harvest |
| Replication | 2 | 27.86 | 63.65 | 144.95 | 47.27 | 68.97 | 53.87 |
| Management | 2 | 1.45 | 54.88 | 57.76 | 232.36* | 158.70 | 138.64* |
| Error (a) | 4 | 3.37 | 10.46 | 10.85 | 21.94 | 27.57 | 17.82 |
| Cultivar | 3 | 8.79 | 97.63 | 1052.48** | 86.27* | 140.08 | 114.84 |
| Error (b) | 6 | 4.38 | 23.15 | 27.31 | 11.25 | 31.44 | 26.72 |
| Management x Cultivar | 6 | 1.74 | 8.68 | 62.16 | 128.46** | 95.47* | 72.68** |
| Error (c) | 12 | 2.11 | 5.52 | 28.68 | 11.48 | 14.39 | 13.12 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 8.** Mean Square from ANOVA of gross return, net return and benefit cost ratio as influenced by crop management practices and cultivars of rice in 2014 at Dhauwadi, Nawalparasi

| Source of variation | df | Gross return | Net return | B:C ratio |
|---|---|---|---|---|
| Replication | 2 | 137.698 | 137.630 | 0.014 |
| Management | 2 | 1593.610* | 6529.978* | 0.924* |
| Error (a) | 4 | 137.662 | 137.634 | 0.015 |
| Cultivar | 3 | 282.739 | 282.774 | 0.030 |
| Error (b) | 6 | 295.536 | 295.508 | 0.033 |
| Management x Cultivar | 6 | 78.221 | 78.245 | 0.009 |
| Error (c) | 12 | 153.965 | 154.007 | 0.017 |

Note: * = significance at 0.05 level of significance; ** = significance at 0.01 level of significance.

**Appendix 9.** Interaction effect of crop management practices and cultivars on straw yield and harvest index of rice in 2014 at Dhauwadi, Nawalparasi

| Treatment | Straw yield (t $ha^{-1}$) (Harvest Index, %) | | | | |
|---|---|---|---|---|---|
| | Cultivars | | | | |
| | Sukkha 3 | Sukkha 4 | Sukkha 5 | Hardinath 2 | Mean (Management) |
| Management | | | | | |
| SRI | $5.05^{bc}$ ($47.73^{bc}$) | $4.86^{bcd}$ ($47.04^{bcd}$) | $5.66^{a}$ ($46.56^{bcd}$) | $4.93^{bcd}$ ($46.49^{bcd}$) | $5.12^{a}$ (46.96) |
| ICM | $5.31^{ab}$ ($43.42^{cd}$) | $4.78^{cd}$ ($45.43^{bcd}$) | $4.25^{e}$ ($48.74^{abc}$) | $4.57^{de}$ ($46.98^{bcd}$) | $4.73^{b}$ (46.14) |
| Conventional | $5.29^{ab}$ ($41.03^{d}$) | $3.65^{f}$ ($51.33^{ab}$) | $3.56^{f}$ ($54.75^{a}$) | $3.76^{f}$ ($48.96^{abc}$) | $4.06^{c}$ (49.02) |
| Mean (cultivars) | $5.21^{a}$ (44.06) | $4.43^{b}$ (47.93) | $4.49^{b}$ (50.02) | $4.42^{b}$ (47.48) | 4.64 (47.37) (Grand mean) |
| $LSD_{(0.05)}$ (Interaction) | 0.421 (5.661) | | | | |
| $LSD_{(0.05)}$ (Cultivars) | 0.373 (ns) | | | | |
| $LSD_{(0.05)}$ (Management) | 0.224 (ns) | | | | |
| SEm (±)(Interaction) | 0.137 (1.837) | | | | |
| SEm (±)(Cultivars) | 0.108 (1.298) | | | | |
| SEm (±)(Management) | 0.056 (0.885) | | | | |
| CV (%) | 5.10 (6.70) | | | | |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05. The figures in parenthesis ( ) indicates harvest index in percentage.

**Appendix 10.** Interaction effect of crop management practices and cultivars on days to panicle initiation and heading of rice in 2014 at Dhauwadi, Nawalparasi

| Treatment | . Panicle initation (days) | | | | | . Heading (days) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cultivars | | | | | Cultivars | | | | |
| | Sukkha 3 | Sukkha 4 | Sukkha 5 | Hardinath 2 | Mean (Management) | Sukkha 3 | Sukkha 4 | Sukkha 5 | Hardinath 2 | Mean (Management) |
| Management | | | | | | | | | | |
| SRI | 55 [e] | 53 [f] | 57 [d] | 45 [i] | 52.75 [c] | 73 [h] | 70 [i] | 77 [f] | 61 [k] | 70.25 [c] |
| ICM | 58 [d] | 56 [e] | 60 [c] | 48 [h] | 55.50 [b] | 78 [e] | 75 [g] | 82 [c] | 66 [j] | 75.50 [b] |
| Conventional | 64 [ab] | 63 [b] | 65 [a] | 50 [g] | 60.50 [a] | 84 [b] | 81 [d] | 90 [a] | 70 [i] | 81.25 [a] |
| Mean (cultivars) | 59.00 [b] | 57.33 [b] | 61.00 a | 47.67 [c] | 56.25 (Grand mean) | 78.33 [b] | 75.33 [c] | 83.00 [a] | 66.00 [d] | 75.67 (Grand mean) |
| $LSD_{(0.05)}$ (Interaction) | 1.089 | | | | | 0.738 | | | | |
| $LSD_{(0.05)}$ (Cultivars) | 1.762 | | | | | 1.893 | | | | |
| $LSD_{(0.05)}$ (Management) | 0.517 | | | | | 0.327 | | | | |
| SEm(±)(Interaction) | 0.354 | | | | | 0.254 | | | | |
| SEm(±)(Cultivars) | 0.509 | | | | | 0.547 | | | | |
| SEm(±)(Management) | 0.132 | | | | | 0.083 | | | | |
| CV (%) | 1.1 | | | | | 0.6 | | | | |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

**Appendix 11.** Interaction effect of crop management practices and cultivars on days to physiological maturity of rice in 2014 at Dhauwadi, Nawalparasi

| Treatment | Days to physiological maturity | | | | |
|---|---|---|---|---|---|
| | Cultivars | | | | |
| | Sukkha 3 | Sukkha 4 | Sukkha 5 | Hardinath 2 | Mean (Management) |
| Management | | | | | |
| SRI | $110^{h}$ | $108^{i}$ | $112^{f}$ | $100^{l}$ | $107.50^{c}$ |
| ICM | $113^{e}$ | $111^{g}$ | $115^{d}$ | $103^{k}$ | $110.50^{b}$ |
| Conventional | $119^{b}$ | $118^{c}$ | $120^{a}$ | $105^{j}$ | $115.50^{a}$ |
| Mean (cultivars) | $114.00^{ab}$ | $112.00^{b}$ | $115.67^{a}$ | $102.67^{c}$ | 111.17 (Grand mean) |
| $LSD_{(0.05)}$ (Interaction) | 0.513 | | | | |
| $LSD_{(0.05)}$ (Cultivars) | 1.970 | | | | |
| $LSD_{(0.05)}$ (Management) | 0.327 | | | | |
| SEm (±) (Interaction) | 0.166 | | | | |
| SEm (±) (Cultivars) | 0.569 | | | | |
| SEm(±)(Management) | 0.083 | | | | |
| CV (%) | 0.3 | | | | |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05.

**Appendix 12.** Interaction effect of crop management practices and cultivars on GDD requirement for days to panicle initiation and physiological maturity of rice in 2014 at Dhauwadi, Nawalparasi

| Treatment | GDD panicle initiation (GDD physiological maturity) | | | | |
|---|---|---|---|---|---|
| | Cultivars | | | | |
| | Sukkha 3 | Sukkha 4 | Sukkha 5 | Hardinath 2 | Mean (Management) |
| Management | | | | | |
| SRI | $1264.62^{f}$ ($2399.15^{h}$) | $1221.17^{g}$ ($2358.28^{i}$) | $1327.98^{e}$ ($2439.00^{g}$) | $1047.78^{i}$ ($2201.35^{k}$) | $1215.39^{c}$ ($2349.45^{c}$) |
| ICM | $1365.37^{d}$ ($2505.00^{e}$) | $1320.95^{e}$ ($2465.00^{f}$) | $1408.82^{c}$ ($2545.93^{d}$) | $1150.03^{h}$ ($2309.83^{j}$) | $1311.29^{b}$ ($2456.44^{b}$) |
| Conventional | $1535.12^{ab}$ ($2696.80^{b}$) | $1512.75^{b}$ ($2676.75^{c}$) | $1557.17^{a}$ ($2717.15^{a}$) | $1232.72^{g}$ ($2400.62^{h}$) | $1459.44^{a}$ ($2622.82^{a}$) |
| Mean (cultivars) | $1388.37^{b}$ ($2533.65^{ab}$) | $1351.62^{c}$ ($2500.01^{b}$) | $1431.32^{a}$ ($2567.36^{a}$) | $1143.51^{d}$ ($2303.93^{c}$) | 1328.71 (2476.24) (Grand mean) |
| $LSD_{(0.05)}$ (Interaction) | 25.35 (10.86) | | | | |
| $LSD_{(0.05)}$ (Cultivars) | 36.04 (38.73) | | | | |
| $LSD_{(0.05)}$ (Management) | 6.91 (6.53) | | | | |
| SEm (±) (Interaction) | 8.227 (3.524) | | | | |
| SEm (±) (Cultivars) | 10.414 (11.191) | | | | |
| SEm (±) (Management) | 1.758 (1.663) | | | | |
| CV (%) | 1.07 (0.25) | | | | |

Treatment means followed by common letter/letters within column are not significantly different among each other based on DMRT at 0.05. The figures in parenthesis ( ) indicates GDD requirement to reach days to physiological maturity.

**Appendix 13.** Genetic coefficients of rice cultivar Sukkha-3 calibrated in different runs in 2014 at Dhauwadi, Nawalparasi, Nepal

| Genetic Coefficients | | | | | | | | | Simulated values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Run no. | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 | A | PM | GY |
| 1 | 540 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 66 | 100 | 3756 |
| 2 | 470 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 64 | 97 | 3435 |
| 3 | 470 | 160 | 490 | 12 | 60 | 0.025 | 1.1 | 1.0 | 64 | 97 | 3981 |
| 4 | 470 | 160 | 490 | 12 | 70 | 0.025 | 1.1 | 1.0 | 64 | 97 | 4463 |
| 5 | 470 | 160 | 490 | 12 | 80 | 0.025 | 1.1 | 1.0 | 64 | 97 | 4897 |
| 6 | 470 | 160 | 490 | 12 | 90 | 0.025 | 1.1 | 1.0 | 64 | 97 | 5152 |
| 7 | 470 | 160 | 490 | 12 | 95 | 0.025 | 1.1 | 1.0 | 64 | 97 | 5180 |
| 8 | 470 | 160 | 490 | 12 | 95 | 0.030 | 1.1 | 1.0 | 64 | 97 | 5385 |
| 9 | 470 | 160 | 490 | 12 | 95 | 0.029 | 1.1 | 1.0 | 64 | 97 | 5353 |
| 10 | 470 | 160 | 470 | 12 | 95 | 0.029 | 1.1 | 1.0 | 64 | 96 | 5300 |
| 11 | 470 | 160 | 470 | 12 | 96 | 0.030 | 1.1 | 1.0 | 64 | 96 | 5305 |
| 12 | 470 | 160 | 470 | 12 | 96 | 0.035 | 1.1 | 1.0 | 64 | 96 | 5330 |
| 13 | 470 | 160 | 470 | 12 | 96 | 0.040 | 1.1 | 1.0 | 64 | 96 | 5335 |
| 14 | 470 | 160 | 470 | 12 | 96 | 0.050 | 1.1 | 1.0 | 64 | 96 | 5337 |
| 15* | 470 | 160 | 470 | 12 | 96 | 0.050 | 1.09 | 1.0 | 64 | 96 | 5357 |

Note: The row with * represents the calibrated genetic coefficients of rice cultivar Sukkha 3. Observed: A, anthesis = 64 days; PM, physiological maturity = 96 days; GY, grain yield = 5354 kg $ha^{-1}$.

**Appendix 14.** Genetic coefficients of rice cultivar Sukkha-4 calibrated in different runs in 2014 at Dhauwadi, Nawalparasi, Nepal

| Genetic Coefficients | | | | | | | | | Simulated values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Run no. | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 | A | PM | GY |
| 1 | 540 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 66 | 100 | 3756 |
| 2 | 500 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 65 | 98 | 3574 |
| 3 | 450 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 63 | 96 | 3287 |
| 4 | 430 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 62 | 95 | 3148 |
| 5 | 410 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 61 | 93 | 2914 |
| 6 | 410 | 160 | 500 | 12 | 50 | 0.025 | 1.1 | 1.0 | 61 | 94 | 2940 |
| 7 | 410 | 160 | 500 | 12 | 60 | 0.025 | 1.1 | 1.0 | 61 | 94 | 3414 |
| 8 | 410 | 160 | 500 | 12 | 70 | 0.025 | 1.1 | 1.0 | 61 | 94 | 3888 |
| 9 | 410 | 160 | 500 | 12 | 90 | 0.025 | 1.1 | 1.0 | 61 | 94 | 4679 |
| 10 | 410 | 160 | 500 | 12 | 95 | 0.025 | 1.1 | 1.0 | 61 | 94 | 4856 |
| 11 | 410 | 160 | 500 | 12 | 97 | 0.025 | 1.1 | 1.0 | 61 | 94 | 4893 |
| 12 | 410 | 160 | 500 | 12 | 97 | 0.035 | 1.1 | 1.0 | 61 | 94 | 5086 |
| 13 | 410 | 160 | 500 | 12 | 97 | 0.030 | 1.1 | 1.0 | 61 | 94 | 5074 |
| 14 | 410 | 160 | 500 | 12 | 97 | 0.028 | 1.1 | 1.0 | 61 | 94 | 5028 |
| 15* | 410 | 160 | 500 | 12 | 97 | 0.028 | 1.09 | 1.0 | 61 | 94 | 5045 |

Note: The row with * represents the calibrated genetic coefficients of rice cultivar Sukkha-4.Observed: A, anthesis = 61 days; PM, physiological maturity = 94 days; GY, grain yield = 5037 kg $ha^{-1}$.

**Appendix 15.** Genetic coefficients of rice cultivar Sukkha-5 calibrated in different runs in 2014 at Dhauwadi, Nawalparasi, Nepal

| Genetic Coefficients | | | | | | | | Simulated values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Run no. | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 | A | PM | GY |
| 1 | 540 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 66 | 100 | 3756 |
| 2 | 560 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 68 | 101 | 3948 |
| 3 | 560 | 160 | 470 | 12 | 50 | 0.025 | 1.1 | 1.0 | 68 | 100 | 3949 |
| 4 | 560 | 160 | 450 | 12 | 50 | 0.025 | 1.1 | 1.0 | 68 | 99 | 3947 |
| 5 | 560 | 160 | 440 | 12 | 50 | 0.025 | 1.1 | 1.0 | 68 | 98 | 3913 |
| 6 | 560 | 160 | 440 | 12 | 70 | 0.025 | 1.1 | 1.0 | 68 | 98 | 4939 |
| 7 | 560 | 160 | 440 | 12 | 90 | 0.025 | 1.1 | 1.0 | 68 | 98 | 5281 |
| 8 | 560 | 160 | 440 | 12 | 94 | 0.025 | 1.1 | 1.0 | 68 | 98 | 5281 |
| 9 | 560 | 160 | 440 | 12 | 94 | 0.030 | 1.1 | 1.0 | 68 | 98 | 5438 |
| 10 | 560 | 160 | 440 | 12 | 94 | 0.040 | 1.1 | 1.0 | 68 | 98 | 5485 |
| 11 | 560 | 160 | 440 | 12 | 94 | 0.040 | 1.09 | 1.0 | 68 | 98 | 5504 |
| 12 | 560 | 160 | 440 | 12 | 94 | 0.040 | 1.00 | 1.0 | 68 | 98 | 5692 |
| 13 | 560 | 160 | 440 | 12 | 94 | 0.040 | 0.90 | 1.0 | 68 | 98 | 5860 |
| 14 | 560 | 160 | 440 | 12 | 94 | 0.040 | 0.95 | 1.0 | 68 | 98 | 5793 |
| 15 | 560 | 160 | 440 | 12 | 94 | 0.040 | 0.98 | 1.0 | 68 | 98 | 5735 |

Note: The row with * represents the calibrated genetic coefficients of rice cultivar Sukkha-5.Observed: A, anthesis = 68 days; PM, physiological maturity = 98 days; GY, grain yield = 5726 kg $ha^{-1}$.

**Appendix 16.** Genetic coefficients of rice cultivar Hardinath-2 calibrated in different runs in 2014 at Dhauwadi, Nawalparasi, Nepal

| Genetic Coefficients | | | | | | | | | Simulated values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Run no. | P1 | P2R | P5 | P20 | G1 | G2 | G3 | G4 | A | PM | GY |
| 1 | 540 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 66 | 100 | 3756 |
| 2 | 450 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 63 | 96 | 3287 |
| 3 | 400 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 61 | 93 | 2927 |
| 4 | 300 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 56 | 89 | 1749 |
| 5 | 250 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 54 | 86 | 1434 |
| 6 | 220 | 160 | 490 | 12 | 50 | 0.025 | 1.1 | 1.0 | 52 | 85 | 1348 |
| 7 | 220 | 160 | 550 | 12 | 50 | 0.025 | 1.1 | 1.0 | 52 | 86 | 1307 |
| 8 | 220 | 160 | 550 | 12 | 70 | 0.025 | 1.1 | 1.0 | 52 | 88 | 1741 |
| 9 | 220 | 160 | 550 | 12 | 90 | 0.025 | 1.1 | 1.0 | 52 | 88 | 2132 |
| 10 | 220 | 160 | 550 | 12 | 96 | 0.025 | 1.1 | 1.0 | 52 | 88 | 2248 |
| 11 | 220 | 160 | 520 | 12 | 96 | 0.025 | 1.1 | 1.0 | 52 | 86 | 2226 |
| 12 | 220 | 160 | 520 | 12 | 96 | 0.030 | 1.1 | 1.0 | 52 | 86 | 2587 |
| 13 | 220 | 160 | 520 | 12 | 96 | 0.050 | 1.1 | 1.0 | 52 | 86 | 3343 |
| 14 | 220 | 160 | 520 | 12 | 96 | 0.070 | 1.1 | 1.0 | 52 | 86 | 3356 |
| 15 | 220 | 160 | 520 | 12 | 96 | 0.070 | 1.0 | 1.0 | 52 | 86 | 3465 |
| 16 | 220 | 160 | 520 | 12 | 96 | 0.070 | 0.8 | 1.0 | 52 | 86 | 3599 |
| 17 | 200 | 180 | 520 | 12 | 96 | 0.07 | 0.8 | 1.0 | 54 | 87 | 3816 |
| 18* | 200 | 180 | 540 | 11.8 | 96 | 0.07 | 0.8 | 1.03 | 56 | 92 | 4726 |

Note: The row with * represents the calibrated genetic coefficients of rice cultivar Hardinath-2. Observed: A, anthesis = 52 days; PM, physiological maturity = 86 days; GY, grain yield = 5003 kg $ha^{-1}$.

**Appendix 19. Minimum data required for calibration and validation of CSM-CERES-Rice model**

| | | |
|---|---|---|
| **1.** | **Site:** | Latitude, Longitude, Elevation, Slope, Aspect |
| **2.** | **Weather:** | Daily maximum and minimum temperature, Solar radiation or sunshine hours, Rainfall, Evaporation, etc. |
| **3.** | **Soil:** | Classification (to family level) the USDA-NRCS taxonomic system, Root growth factor, Drainage coefficient |
| **4.** | **Physical properties:** | Percentage sand, silt and clay up to 100 cm soil depths (layer wise), Bulk density (layer wise) |
| **5.** | **Chemical properties:** | pH, Organic carbon, total Nitrogen |
| **6.** | **Initial conditions:** | Information to be taken before crop sowing from field<br>• KCl extractable ammonium and nitrate N at various depths.<br>• Soil moisture content at various depths.<br>• Date and depth of residue incorporation (material type, amount and N concentration. |
| **7.** | **Establishment:** | Date of transplanting, row spacing, no. of plants per square meter |
| **8.** | **Irrigation:** | Date and Amount |
| **9.** | **N fertilizer:** | Schedule, Source and amount, Depth and placement of incorporation |
| **10.** | **Phenological events recorded:** | • Emergence<br>• Days to Anthesis<br>• Days to physiological maturity |
| **11.** | **Monitoring and recording:** | Monitoring and recording of LAI at different stages of growth |
| **12.** | **Recording:** | Recording of dried biomass (tops weight other than root of whole plant) at different stages of growth |
| **13.** | **Yield and its components:** | • Grain yield<br>• Number of effective tillers per $m^{-2}$<br>• Grain number per spike<br>• Thousand grain weight |

**Appendix 20. 'X' (IAAS1401.RIX) file for rice with different management practices and cultivars in Dhauwadi, Nawalparasi**

```
*EXP.DETAILS: IAAS1401RI EFFECT OF MANAGMENT PRACTICES ON CULTIVARS OF RICE

*GENERAL

@PEOPLE

BishalDhakal

@ADDRESS

IAAS Kritipur

@SITE

Nawalparasi

@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........

    210     8     6   -99    50  STRI   5.5     4   5.5 manual


*TREATMENTS                        -------------FACTOR LEVELS------------

@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM

 1 1 1 0 SRI Sukkha 3               1  1  1  1  1  1  1  1  0  1  0  8  1

 2 1 1 0 SRI Sukkha 4               2  1  1  1  1  1  1  1  0  1  0  7  1

 3 1 1 0 SRI Sukkha 5               3  1  1  1  1  1  1  1  0  1  0  9  1

 4 1 1 0 SRI hardinath 2            4  1  1  1  1  1  1  1  0  1  0  3  1
```

```
 5 1 1 0 ICM Sukkha 3               1  1  1  1  2  2  2  2  0  1  0  6  1
 6 1 1 0 ICM Sukkha 4               2  1  1  1  2  2  2  2  0  1  0  4  1
 7 1 1 0 ICM Sukkha 5               3  1  1  1  2  2  2  2  0  1  0  7  1
 8 1 1 0 ICM Hardinath 2            4  1  1  1  2  2  2  2  0  1  0  2  1
 9 1 1 0 Con Sukkha 2               1  1  1  1  3  3  3  0  0  1  0  5  1
10 1 1 0 Con Sukkha 4               2  1  1  1  3  3  3  0  0  1  0  4  1
11 1 1 0 Con Sukkha 5               3  1  1  1  3  3  3  0  0  1  0  6  1
12 1 1 0 Con Hardinath 2            4  1  1  1  3  3  3  0  0  1  0  1  1

*CULTIVARS
@C CR INGENO CNAME
 1 RI IB0101 Sukkha 3
 2 RI IB0102 Sukkha 4
 3 RI IB0103 Sukkha 5
 4 RI IB0104 Hardinath 2

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 IAAS1401 NAWA       -99   -99 DR000   -99   -99   -99 L      -99  IAAS140001 -99
```

```
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1             -99             -99       -99               -99   -99   -99   -99   -99   -99

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 14184 SA011 SA001 SA015  -99
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    20   1.6  1.38   .12   5.5   -99  78.3 285.9   -99
 1    40   1.6    .9   .08   4.9   -99  34.7 254.6   -99
 1    60   1.5   .73   .06   4.8   -99  30.4 245.6   -99
 1    80   1.5   .67   .06   4.7   -99  43.8 245.6   -99
 1   100   1.6   .65   .06   4.7   -99  29.9 232.3   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    MZ 14183   -99   -99     1     1   -99   -99   -99   -99   -99   -99 No residue
@C  ICBL  SH2O  SNH4  SNO3
 1    20  .264 .0097 .0167
 1    40  .254 .0063 .0103
```

```
 1    60  .239 .0053 .0097
 1    80  .246 .0053 .0097
 1   100  .258 .0053 .0097

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE   ENV  PLPH  SPRL                        PLNAME
 1 14185   -99    16    16     T     H    25   -99     5   -99    14  33.2     1   -99                           SRI
 2 14185   -99    25    25     T     H    20   -99     5   -99    21  33.2     2   -99                           ICM
 3 14185   -99 33.33 33.33     T     H    20   -99     5   -99    28  33.2     3   -99                           CON

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1     1    30    50   100 GS000 IR001    10 SRI irrigation
@I IDATE  IROP IRVAL
 1 14208 IR003   4.9
 1 14215 IR003   4.9
 1 14222 IR003   4.9
 1 14227 IR003   4.9
 1 14235 IR003   4.9
```

```
 1 14249 IR003   4.9
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 2     1    30    50   100 GS000 IR001    10 ICM irrigation
@I IDATE  IROP IRVAL
 2 14188 IR003    32
 2 14191 IR003    16
 2 14198 IR003  24.1
 2 14204 IR003  19.4
 2 14209 IR003    49
 2 14214 IR003  38.3
 2 14219 IR003  22.9
 2 14224 IR003  21.2
 2 14231 IR003  31.9
 2 14243 IR003  17.8
 2 14247 IR003  47.6
 2 14254 IR003  31.3
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 3     1    30    50   100 GS000 IR001    10 Con irrigation
@I IDATE  IROP IRVAL
```

| | | | |
|---|---|---|---|
| 3 | 14188 | IR003 | 45.9 |
| 3 | 14192 | IR003 | 35.7 |
| 3 | 14197 | IR003 | 40.7 |
| 3 | 14201 | IR003 | 39.2 |
| 3 | 14204 | IR003 | 32.9 |
| 3 | 14208 | IR003 | 51.2 |
| 3 | 14211 | IR003 | 30.6 |
| 3 | 14214 | IR003 | 39.3 |
| 3 | 14219 | IR003 | 53 |
| 3 | 14224 | IR003 | 49.3 |
| 3 | 14231 | IR003 | 60 |
| 3 | 14235 | IR003 | 15.2 |
| 3 | 14242 | IR003 | 22.9 |
| 3 | 14245 | IR003 | 39.8 |
| 3 | 14247 | IR003 | 32.7 |
| 3 | 14251 | IR003 | 35.3 |
| 3 | 14254 | IR003 | 34.6 |

*FERTILIZERS (INORGANIC)

```
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 14185 FE006 AP012     0     6    15     0   -99   -99   -99 SRI Fertilizer
 1 14185 FE005 AP012     0     4     0     0   -99   -99   -99 SRI Fertilizer
 1 14185 FE016 AP012     0     0     0    10   -99   -99   -99 SRI Fertilizer
 1 14215 FE005 AP012     0     5     0     0   -99   -99   -99 SRI Fertilizer
 1 14231 FE005 AP012     0     5     0     0   -99   -99   -99 SRI Fertilizer
 2 14185 FE006 AP012     0    12    30     0   -99   -99   -99 ICM Fertilizer
 2 14185 FE005 AP012     0     8     0     0   -99   -99   -99 ICM Fertilizer
 2 14185 FE016 AP012     0     0     0    20   -99   -99   -99 ICM Fertilizer
 2 14215 FE005 AP012     0    10     0     0   -99   -99   -99 ICM Fertilizer
 2 14227 FE005 AP012     0    10     0     0   -99   -99   -99 ICM Fertilizer
 3 14185 FE005 AP012     0    17     0     0   -99   -99   -99 Con Fertilizer
 3 14185 FE016 AP012     0     0     0    40   -99   -99   -99 Con Fertilizer
 3 14185 FE006 AP012     0    23    60     0   -99   -99   -99 Con Fertilizer
 3 14215 FE005 AP012     0    20     0     0   -99   -99   -99 Con Fertilizer
 3 14225 FE005 AP012     0    20     0     0   -99   -99   -99 Con Fertilizer

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
```

```
 1 14185 RE003 10000   1.5    .5   1.5   100    15 AP002 SRI OM
 2 14185 RE003  5000   1.5    .5   1.5   100    15 AP002 ICM OM

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 14185   -99   -99   -99   -99   -99  -99

*TILLAGE AND ROTATIONS
@T TDATE TIMPL  TDEP TNAME
 1 14184 TI042    30 -99
 1 14185 TI021    15 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 14261 GS006     H     A   100   -99 Harvest 1st
 2 14266 GS006     H     A   100   -99 Harvest 2nd
 3 14270 GS006     H     A   100   -99 Harvest 3rd
 4 14274 GS006     H     A   100   -99 Harvest 4th
 5 14275 GS006     H     A   100   -99 Harvest 5th
```

```
 6 14276 GS006     H     A   100   -99 Harvest 6th
 7 14278 GS006     H     A   100   -99 Harvest 7th
 8 14280 GS006     H     A   100   -99 Harvest 8th
 9 14282 GS006     H     A   100   -99 Harvest 9th

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 14184  2150 DEFAULT SIMULATION CONTR  RICER
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     YY     N     NNN     Y     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
1 MA              R     RRR     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     YYYY     N     Y     N     Y

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
```

```
 1 PL          14001 14001    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 01001   100     0
```

**Appendix 21. 'A' (IAAS1401.RIA) file for rice with different management practices and cultivars in Dhauwadi, Nawalparasi**

*EXP. DATA (A): IAAS1401RI EFFECT OF MANAGMENT PRACTICES ON CULTIVARS OF RICE time course (A) data

! File last edited on day 12/24/2015 at 3:51:32 PM

| @TRNO | HWAM | HWUM | H#AM | H#UM | LAIX | CWAM | BWAH | ADAT | MDAT |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5354 | 0.023 | 56211 | 169 | 4.833 | 10401 | 5046 | 249 | 281 |
| 2 | 5037 | 0.023 | 50099 | 167 | 4.391 | 9900 | 4862 | 246 | 279 |
| 3 | 5726 | 0.026 | 62698 | 183 | 4.532 | 11384 | 5658 | 253 | 283 |
| 4 | 5003 | 0.024 | 42672 | 150 | 3.911 | 9930 | 4927 | 237 | 271 |
| 5 | 4751 | 0.024 | 37914 | 142 | 4.759 | 10060 | 5309 | 247 | 277 |
| 6 | 4659 | 0.022 | 35368 | 134 | 3.478 | 9440 | 4780 | 244 | 275 |
| 7 | 4770 | 0.024 | 59756 | 165 | 4.709 | 9022 | 4253 | 251 | 279 |
| 8 | 4719 | 0.021 | 33848 | 133 | 3.933 | 9289 | 4570 | 235 | 267 |
| 9 | 4277 | 0.023 | 29966 | 127 | 4.379 | 9562 | 5285 | 246 | 276 |
| 10 | 4493 | 0.022 | 27625 | 125 | 3.792 | 8147 | 3654 | 243 | 275 |
| 11 | 4984 | 0.023 | 37011 | 147 | 3.325 | 8543 | 3559 | 252 | 277 |
| 12 | 4197 | 0.021 | 23191 | 115 | 3.101 | 7955 | 3758 | 232 | 262 |

**Appendix 22. 'S' (IAAS140001.soil.sol) file used in CERES-RICE model representing the chemical and physical properties of soil under rice experiment in Dhauwadi, Nawalparasi**

```
*SOILS: General DSSAT Soil Input File
*IAAS140001  -99            L    100 Loam
@SITE        COUNTRY          LAT     LONG SCS FAMILY
Nawalparasi Nepal          27.679  84.083 Spodosol
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN   .13     6    .4    73     1     1 IB001 IB001IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    20   -99  .126  .295  .357     1  1.32  1.62  1.38  12.5  47.9   -99   .12   5.5   -99   -99   -99
    40   -99  .138    .3  .383  .549  1.32  1.56    .9  17.5  48.9   -99   .08   4.9   -99   -99   -99
    60   -99  .124  .276  .417  .368  1.32  1.47   .73  15.6  46.7   -99   .06   4.8   -99   -99   -99
    80   -99   .13   .28  .399  .247  1.32  1.52   .67  17.1  45.9   -99   .06   4.7   -99   -99   -99
   100   -99  .119  .263  .378  .165  1.32  1.58   .65  15.1  43.9   -99   .06   4.7   -99   -99   -99
```

**Appendix 23. 'T' (IAAS1401.RIT) file for rice with different management practices and cultivars in Dhauwadi, Nawalparasi**

```
*EXP. DATA (T): IAAS1401RI EFFECT OF MANAGMENT PRACTICES ON CULTIVARS OF
RICE observed (T) data
! File last edited on day 12/24/2015 at 3:57:42 PM
@TRNO   DATE  T#AD  LAID  RWAD  SWAD  GWAD  LWAD  CWAD
     1 14215 471.1 2.138   -99   -99   -99   -99  2047
     1 14230 408.8 4.175   -99   -99   -99   -99  6228
     1 14245 377.7 4.833   -99   -99   -99   -99 10000
     1 14260 384.4   -99   -99   -99   -99   -99  8222
     1 14275 355.5   -99   -99   -99   -99   -99  9168
     1 14281 355.5   -99   -99   -99  5354   -99  9651
     2 14215 502.2 1.782   -99   -99   -99   -99  1524
     2 14230 413.3 4.216   -99   -99   -99   -99  4033
     2 14245 342.2 4.391   -99   -99   -99   -99  7667
     2 14260   320   -99   -99   -99   -99   -99  8056
     2 14275   320   -99   -99   -99   -99   -99  8735
     2 14279   320   -99   -99   -99  5037   -99  9194
     3 14215 451.1 2.285   -99   -99   -99   -99  1862
     3 14230 424.4 4.532   -99   -99   -99   -99  4328
     3 14245 337.7 3.893   -99   -99   -99   -99  6722
     3 14260 351.1   -99   -99   -99   -99   -99 11389
     3 14275 357.7   -99   -99   -99   -99   -99 10053
     3 14283 357.7   -99   -99   -99  5726   -99 10582
     4 14215 402.2 1.993   -99   -99   -99   -99  2122
     4 14230 333.3 3.478   -99   -99   -99   -99  5478
     4 14245 295.5 3.911   -99   -99   -99   -99  6278
     4 14260 295.5   -99   -99   -99   -99   -99  8768
     4 14271 288.9   -99   -99   -99  5003   -99  9230
```

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 4 | 14275 | -99 | -99 | -99 | -99 | -99 | -99 | -99 |
| 5 | 14215 | 393.3 | 1.846 | -99 | -99 | -99 | -99 | 1679 |
| 5 | 14230 | 391.7 | 4.759 | -99 | -99 | -99 | -99 | 5042 |
| 5 | 14245 | 295 | 4.5 | -99 | -99 | -99 | -99 | 7833 |
| 5 | 14260 | 285 | -99 | -99 | -99 | -99 | -99 | 8517 |
| 5 | 14275 | 271.7 | -99 | -99 | -99 | -99 | -99 | 9207 |
| 5 | 14277 | 271.7 | -99 | -99 | -99 | 4751 | -99 | 9395 |
| 6 | 14215 | 356.7 | 1.514 | -99 | -99 | -99 | -99 | 1308 |
| 6 | 14230 | 358.3 | 3.478 | -99 | -99 | -99 | -99 | 5213 |
| 6 | 14245 | 266.7 | 3.144 | -99 | -99 | -99 | -99 | 5750 |
| 6 | 14260 | 278.3 | -99 | -99 | -99 | -99 | -99 | 7917 |
| 6 | 14275 | 278.3 | -99 | -99 | -99 | 4659 | -99 | 8787 |
| 6 | 14275 | 278.3 | -99 | -99 | -99 | 4659 | -99 | 8787 |
| 7 | 14215 | 485 | 1.255 | -99 | -99 | -99 | -99 | 903 |
| 7 | 14230 | 473.3 | 3.769 | -99 | -99 | -99 | -99 | 4154 |
| 7 | 14245 | 406.7 | 4.709 | -99 | -99 | -99 | -99 | 5833 |
| 7 | 14260 | 403.3 | -99 | -99 | -99 | -99 | -99 | 7733 |
| 7 | 14275 | 383.3 | -99 | -99 | -99 | -99 | -99 | 7937 |
| 7 | 14279 | 383.3 | -99 | -99 | -99 | 4770 | -99 | 8355 |
| 8 | 14215 | 358.3 | 1.167 | -99 | -99 | -99 | -99 | 1149 |
| 8 | 14230 | 308.3 | 3.392 | -99 | -99 | -99 | -99 | 4729 |
| 8 | 14245 | 253.3 | 3.933 | -99 | -99 | -99 | -99 | 8563 |
| 8 | 14260 | 253.3 | -99 | -99 | -99 | -99 | -99 | 8197 |
| 8 | 14267 | 260 | -99 | -99 | -99 | 4719 | -99 | 8629 |
| 8 | 14275 | -99 | -99 | -99 | -99 | -99 | -99 | -99 |
| 9 | 14215 | 266.7 | 1.203 | -99 | -99 | -99 | -99 | 956 |
| 9 | 14230 | 307.2 | 2.865 | -99 | -99 | -99 | -99 | 3381 |
| 9 | 14245 | 273.7 | 4.379 | -99 | -99 | -99 | -99 | 5840 |
| 9 | 14260 | 265.6 | -99 | -99 | -99 | -99 | -99 | 9253 |
| 9 | 14275 | 265.6 | -99 | -99 | -99 | -99 | -99 | 8784 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 14276 | 265.6 | -99 | -99 | -99 | 4277 | -99 | 8963 |
| 10 | 14215 | 232.5 | 0.956 | -99 | -99 | -99 | -99 | 822 |
| 10 | 14230 | 307.2 | 2.515 | -99 | -99 | -99 | -99 | 3069 |
| 10 | 14245 | 229.7 | 3.792 | -99 | -99 | -99 | -99 | 6840 |
| 10 | 14260 | 234.7 | -99 | -99 | -99 | -99 | -99 | 7600 |
| 10 | 14275 | 234.7 | -99 | -99 | -99 | 4493 | -99 | 7518 |
| 10 | 14275 | 234.7 | -99 | -99 | -99 | 4493 | -99 | 7518 |
| 11 | 14215 | 218.5 | 0.768 | -99 | -99 | -99 | -99 | 757 |
| 11 | 14230 | 309.3 | 2.25 | -99 | -99 | -99 | -99 | 3131 |
| 11 | 14245 | 287.9 | 3.325 | -99 | -99 | -99 | -99 | 5973 |
| 11 | 14260 | 264.5 | -99 | -99 | -99 | -99 | -99 | 5760 |
| 11 | 14275 | 264.5 | -99 | -99 | -99 | -99 | -99 | 7689 |
| 11 | 14277 | 264.5 | -99 | -99 | -99 | 4984 | -99 | 7846 |
| 12 | 14215 | 261.3 | 1.083 | -99 | -99 | -99 | -99 | 1097 |
| 12 | 14230 | 247.5 | 3.101 | -99 | -99 | -99 | -99 | 3955 |
| 12 | 14245 | 215.5 | 2.909 | -99 | -99 | -99 | -99 | 5720 |
| 12 | 14260 | 215.5 | -99 | -99 | -99 | -99 | -99 | 6999 |
| 12 | 14262 | 211.2 | -99 | -99 | -99 | 4197 | -99 | 7368 |
| 12 | 14275 | -99 | -99 | -99 | -99 | -99 | -99 | -99 |

**Appendix 24. 'W' (NAWA1401.WTH) file for running experimental files in CSM-CERES-Rice for Dhauwadi, Nawalparasi**

```
*WEATHER DATA : NAWA
@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  NAWA   27.679   84.083   280  19.0   5.9   2.0  10.0
@DATE  SRAD  TMAX  TMIN  RAIN  DEWP  WIND   RHUM
14152  25.3  41.2  28.1   0.2  14.9 190.1   30.5
14153  25.5  42.1  28.1   0.0  14.3 190.1   28.7
14154  20.2  43.5  28.2   1.4  12.9 216.0   24.8
14155  25.9  44.5  29.2   0.0   9.2 164.2   18.3
14156  25.6  44.5  28.7   2.5  12.1 172.8   22.1
14157  25.1  44.9  30.0   3.6  13.3 224.6   23.3
14158  12.9  44.6  31.4   8.3  17.3 311.0   30.1
14159  21.8  44.8  30.8   7.2  15.6 267.8   26.9
14160  23.9  45.4  29.1  19.8  11.7 267.8   21.0
14161  26.1  45.8  29.4   0.7  10.9 276.5   19.9
14162  25.3  45.1  28.8   1.2  12.4 224.6   22.4
14163  24.8  44.4  28.6   1.3   7.4 190.1   16.1
14164  26.8  45.0  30.4   0.0   8.9 337.0   17.3
14165  23.6  43.8  30.6   0.0  13.0 293.8   23.1
14166  22.4  42.0  31.0   0.0  15.7 190.1   28.9
14167  23.6  41.3  29.6  15.7  18.1 267.8   35.7
14168  19.7  41.5  31.9  15.7  18.6 190.1   35.1
14169  22.2  41.7  31.5   1.6  18.0 164.2   33.6
14170  17.7  42.0  31.4   2.0  18.2 207.4   33.5
14171  12.8  44.1  32.9   7.1  17.3 216.0   29.3
14172   5.8  43.2  33.5  21.1  18.2 190.1   31.4
14173  18.5  44.5  31.1   1.3  16.1 267.8   28.0
14174  20.2  44.6  32.4  18.5  13.6 293.8   22.8
```

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 14175 | 25.3 | 43.4 | 31.8 | 4.2 | 15.5 | 207.4 | 27.1 |
| 14176 | 25.4 | 42.4 | 32.2 | 8.5 | 17.0 | 181.4 | 30.0 |
| 14177 | 22.9 | 42.7 | 32.5 | 7.7 | 17.0 | 172.8 | 29.7 |
| 14178 | 22.6 | 43.6 | 32.2 | 6.3 | 16.5 | 216.0 | 28.4 |
| 14179 | 18.0 | 43.1 | 32.8 | 11.4 | 16.9 | 267.8 | 28.9 |
| 14180 | 17.0 | 44.4 | 33.7 | 23.8 | 16.6 | 293.8 | 27.1 |
| 14181 | 13.5 | 43.8 | 32.2 | 13.9 | 16.8 | 216.0 | 27.9 |
| 14182 | 18.1 | 40.2 | 29.8 | 4.8 | 19.8 | 337.0 | 40.2 |
| 14183 | 16.0 | 34.0 | 28.3 | 1.6 | 22.2 | 103.7 | 58.5 |
| 14184 | 17.2 | 39.2 | 28.9 | 14.3 | 21.0 | 172.8 | 46.7 |
| 14185 | 6.2 | 37.6 | 28.8 | 28.3 | 20.4 | 216.0 | 47.5 |
| 14186 | 11.0 | 36.2 | 27.8 | 5.7 | 23.0 | 224.6 | 61.4 |
| 14187 | 15.2 | 34.5 | 27.1 | 0.0 | 24.2 | 362.9 | 69.3 |
| 14188 | 11.6 | 35.5 | 27.6 | 5.8 | 23.4 | 267.8 | 61.6 |
| 14189 | 17.5 | 39.2 | 28.0 | 3.8 | 21.8 | 146.9 | 49.2 |
| 14190 | 17.4 | 38.8 | 28.8 | 7.9 | 22.4 | 216.0 | 51.8 |
| 14191 | 19.2 | 38.4 | 29.1 | 10.8 | 22.4 | 155.5 | 51.3 |
| 14192 | 6.5 | 37.1 | 28.7 | 13.3 | 23.5 | 198.7 | 58.5 |
| 14193 | 18.9 | 37.2 | 28.0 | 34.9 | 24.4 | 155.5 | 61.4 |
| 14194 | 11.3 | 36.4 | 29.3 | 3.2 | 23.8 | 216.0 | 58.7 |
| 14195 | 16.2 | 38.9 | 28.4 | 6.1 | 23.3 | 250.6 | 55.3 |
| 14196 | 13.0 | 32.5 | 27.8 | 10.7 | 24.5 | 328.3 | 71.7 |
| 14197 | 14.1 | 33.8 | 27.2 | 0.0 | 23.3 | 388.8 | 65.5 |
| 14198 | 17.0 | 36.1 | 26.8 | 4.2 | 24.0 | 250.6 | 68.5 |
| 14199 | 15.7 | 35.1 | 26.4 | 20.9 | 24.8 | 362.9 | 73.0 |
| 14200 | 18.2 | 34.6 | 26.6 | 8.8 | 24.9 | 276.5 | 71.2 |
| 14201 | 18.3 | 37.2 | 27.2 | 3.4 | 24.4 | 250.6 | 63.6 |
| 14202 | 18.1 | 34.8 | 27.7 | 10.0 | 24.4 | 233.3 | 68.8 |
| 14203 | 20.6 | 37.1 | 26.2 | 9.8 | 23.3 | 501.1 | 61.9 |
| 14204 | 10.6 | 35.4 | 26.6 | 4.7 | 22.7 | 414.7 | 63.2 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 14205 | 9.7 | 35.4 | 26.4 | 3.6 | 22.7 | 241.9 | 62.6 |
| 14206 | 20.0 | 35.9 | 25.8 | 1.6 | 23.3 | 155.5 | 63.9 |
| 14207 | 21.5 | 35.0 | 26.9 | 0.3 | 23.6 | 121.0 | 62.8 |
| 14208 | 7.8 | 34.3 | 28.0 | 13.8 | 23.7 | 172.8 | 64.1 |
| 14209 | 23.9 | 36.4 | 26.8 | 3.7 | 23.5 | 181.4 | 62.7 |
| 14210 | 21.9 | 37.2 | 27.0 | 12.4 | 23.9 | 216.0 | 61.5 |
| 14211 | 19.4 | 36.5 | 27.5 | 8.7 | 23.9 | 259.2 | 62.9 |
| 14212 | 21.3 | 37.0 | 27.4 | 3.6 | 23.8 | 285.1 | 61.2 |
| 14213 | 17.6 | 37.8 | 27.4 | 2.2 | 23.4 | 224.6 | 57.9 |
| 14214 | 18.9 | 38.2 | 27.9 | 7.3 | 23.5 | 198.7 | 57.1 |
| 14215 | 15.3 | 31.4 | 26.3 | 32.4 | 25.1 | 190.1 | 78.4 |
| 14216 | 19.0 | 35.9 | 25.1 | 0.9 | 23.0 | 190.1 | 63.4 |
| 14217 | 20.4 | 36.6 | 27.6 | 0.4 | 23.4 | 509.8 | 60.9 |
| 14218 | 17.9 | 36.9 | 26.6 | 0.0 | 23.1 | 423.4 | 60.9 |
| 14219 | 15.3 | 34.9 | 26.9 | 0.9 | 24.0 | 121.0 | 67.0 |
| 14220 | 16.5 | 35.5 | 27.1 | 14.8 | 24.1 | 129.6 | 65.8 |
| 14221 | 17.8 | 37.2 | 28.1 | 13.2 | 23.3 | 129.6 | 58.3 |
| 14222 | 12.7 | 35.5 | 28.1 | 0.0 | 23.8 | 138.2 | 62.5 |
| 14223 | 20.0 | 35.8 | 27.6 | 3.7 | 24.0 | 181.4 | 63.7 |
| 14224 | 18.1 | 34.6 | 27.8 | 9.6 | 24.2 | 233.3 | 65.7 |
| 14225 | 6.4 | 37.4 | 28.1 | 59.6 | 23.9 | 397.4 | 61.3 |
| 14226 | 3.3 | 35.8 | 27.5 | 32.6 | 24.1 | 285.1 | 65.4 |
| 14227 | 8.6 | 34.1 | 26.6 | 0.1 | 23.9 | 164.2 | 68.7 |
| 14228 | 17.2 | 35.0 | 26.5 | 0.1 | 23.2 | 267.8 | 64.8 |
| 14229 | 17.4 | 36.0 | 26.8 | 2.8 | 22.0 | 259.2 | 57.1 |
| 14230 | 14.9 | 38.3 | 27.1 | 6.8 | 20.4 | 207.4 | 48.6 |
| 14231 | 13.5 | 38.5 | 27.1 | 10.8 | 19.3 | 250.6 | 45.8 |
| 14232 | 8.7 | 38.3 | 27.0 | 18.8 | 19.9 | 121.0 | 46.8 |
| 14233 | 6.0 | 37.9 | 27.2 | 18.4 | 21.1 | 181.4 | 50.2 |
| 14234 | 20.8 | 39.6 | 27.7 | 8.2 | 19.8 | 103.7 | 44.3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 14235 | 19.1 | 38.9 | 27.5 | 15.9 | 19.8 | 164.2 | 45.0 |
| 14236 | 14.9 | 40.0 | 28.6 | 26.8 | 19.5 | 233.3 | 43.3 |
| 14237 | 16.0 | 39.7 | 28.8 | 24.7 | 18.6 | 172.8 | 40.7 |
| 14238 | 15.2 | 39.0 | 27.2 | 31.4 | 19.5 | 207.4 | 45.0 |
| 14239 | 17.5 | 38.2 | 26.9 | 2.0 | 19.4 | 172.8 | 45.4 |
| 14240 | 18.5 | 36.3 | 27.4 | 2.9 | 21.1 | 224.6 | 53.6 |
| 14241 | 21.6 | 32.0 | 26.3 | 9.8 | 23.5 | 146.9 | 70.7 |
| 14242 | 21.3 | 35.0 | 26.8 | 5.3 | 23.2 | 190.1 | 63.6 |
| 14243 | 18.5 | 34.5 | 25.1 | 4.7 | 22.2 | 345.6 | 63.4 |
| 14244 | 14.1 | 30.8 | 25.1 | 0.5 | 22.7 | 345.6 | 74.9 |
| 14245 | 21.7 | 34.6 | 25.1 | 2.4 | 23.0 | 380.2 | 68.3 |
| 14246 | 20.3 | 34.7 | 25.4 | 3.5 | 23.4 | 302.4 | 67.7 |
| 14247 | 22.3 | 36.1 | 25.6 | 0.0 | 22.5 | 207.4 | 60.1 |
| 14248 | 21.2 | 36.6 | 26.9 | 18.3 | 21.9 | 155.5 | 56.2 |
| 14249 | 21.0 | 36.0 | 27.1 | 10.0 | 22.9 | 155.5 | 60.5 |
| 14250 | 18.3 | 36.5 | 26.8 | 1.1 | 22.6 | 285.1 | 60.3 |
| 14251 | 18.5 | 35.0 | 26.7 | 11.8 | 22.7 | 311.0 | 63.3 |
| 14252 | 17.6 | 32.6 | 26.4 | 5.8 | 22.6 | 198.7 | 67.1 |
| 14253 | 15.9 | 31.6 | 25.4 | 10.2 | 22.6 | 216.0 | 70.4 |
| 14254 | 18.3 | 32.1 | 25.2 | 6.8 | 23.0 | 207.4 | 71.8 |
| 14255 | 19.4 | 33.5 | 24.8 | 19.1 | 22.6 | 172.8 | 67.7 |
| 14256 | 12.1 | 32.6 | 25.6 | 2.1 | 22.7 | 138.2 | 68.0 |
| 14257 | 6.1 | 33.0 | 25.6 | 14.0 | 23.3 | 138.2 | 70.7 |
| 14258 | 7.5 | 31.9 | 25.4 | 12.8 | 23.3 | 155.5 | 74.3 |
| 14259 | 18.9 | 32.1 | 24.7 | 5.0 | 23.5 | 181.4 | 74.8 |
| 14260 | 20.6 | 36.2 | 25.7 | 0.0 | 22.6 | 129.6 | 62.6 |
| 14261 | 21.4 | 37.7 | 26.0 | 1.5 | 21.0 | 138.2 | 53.4 |
| 14262 | 20.8 | 38.2 | 27.0 | 26.3 | 20.6 | 155.5 | 50.6 |
| 14263 | 12.3 | 33.4 | 25.9 | 2.0 | 22.5 | 216.0 | 65.6 |
| 14264 | 17.1 | 35.2 | 25.0 | 0.8 | 22.0 | 121.0 | 62.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 14265 | 16.1 | 36.5 | 24.5 | 0.0 | 18.2 | 233.3 | 50.2 |
| 14266 | 13.5 | 36.2 | 22.6 | 0.0 | 15.7 | 190.1 | 43.5 |
| 14267 | 14.6 | 36.4 | 24.5 | 0.8 | 17.2 | 181.4 | 45.5 |
| 14268 | 7.3 | 35.6 | 24.9 | 0.2 | 19.3 | 172.8 | 52.1 |
| 14269 | 18.5 | 36.3 | 23.3 | 0.0 | 16.0 | 224.6 | 44.2 |
| 14270 | 17.8 | 36.1 | 22.8 | 0.0 | 15.4 | 216.0 | 43.1 |
| 14271 | 18.6 | 36.5 | 23.9 | 0.0 | 16.4 | 164.2 | 44.0 |
| 14272 | 18.3 | 34.0 | 22.8 | 1.0 | 15.9 | 190.1 | 46.5 |
| 14273 | 9.5 | 33.7 | 22.6 | 0.0 | 16.2 | 172.8 | 48.7 |
| 14274 | 20.2 | 35.8 | 22.6 | 0.0 | 15.9 | 146.9 | 45.8 |
| 14275 | 20.9 | 36.3 | 23.0 | 0.0 | 15.5 | 164.2 | 43.5 |
| 14276 | 19.4 | 36.3 | 23.6 | 0.0 | 15.2 | 164.2 | 42.3 |
| 14277 | 19.3 | 36.2 | 23.7 | 0.0 | 16.0 | 164.2 | 43.7 |
| 14278 | 19.8 | 36.8 | 23.7 | 0.0 | 16.6 | 146.9 | 44.9 |
| 14279 | 20.1 | 37.5 | 24.2 | 0.0 | 17.1 | 164.2 | 45.3 |
| 14280 | 20.4 | 37.2 | 24.1 | 0.0 | 16.4 | 172.8 | 43.2 |
| 14281 | 20.3 | 36.7 | 23.8 | 0.0 | 15.1 | 164.2 | 41.6 |
| 14282 | 19.6 | 36.6 | 23.3 | 0.0 | 15.0 | 181.4 | 41.5 |
| 14283 | 19.1 | 36.9 | 23.4 | 0.0 | 13.6 | 181.4 | 38.3 |
| 14284 | 20.1 | 36.5 | 21.7 | 0.0 | 12.2 | 164.2 | 37.0 |
| 14285 | 19.3 | 36.7 | 21.0 | 0.6 | 14.4 | 207.4 | 42.4 |
| 14286 | 4.4 | 29.1 | 22.9 | 23.1 | 18.6 | 267.8 | 65.1 |
| 14287 | 1.4 | 27.8 | 21.3 | 31.3 | 21.1 | 449.3 | 81.1 |
| 14288 | 16.9 | 30.0 | 20.4 | 0.0 | 20.1 | 172.8 | 75.1 |
| 14289 | 15.1 | 30.7 | 18.9 | 0.0 | 17.2 | 190.1 | 64.8 |
| 14290 | 18.5 | 31.3 | 19.1 | 0.0 | 14.9 | 181.4 | 55.4 |
| 14291 | 19.2 | 31.1 | 19.0 | 0.0 | 12.0 | 164.2 | 46.5 |
| 14292 | 18.9 | 31.2 | 18.1 | 0.0 | 11.7 | 216.0 | 47.1 |
| 14293 | 19.0 | 31.3 | 17.6 | 0.0 | 12.3 | 146.9 | 47.8 |
| 14294 | 18.8 | 31.9 | 18.9 | 0.0 | 13.0 | 138.2 | 47.1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 14295 | 18.8 | 31.9 | 20.0 | 0.0 | 13.7 | 146.9 | 48.9 |
| 14296 | 18.4 | 31.9 | 20.7 | 0.0 | 14.4 | 172.8 | 50.8 |
| 14297 | 18.5 | 31.4 | 19.4 | 0.0 | 13.4 | 138.2 | 49.2 |
| 14298 | 17.0 | 31.6 | 20.0 | 1.8 | 13.7 | 121.0 | 48.4 |
| 14299 | 18.0 | 30.6 | 20.2 | 0.0 | 14.1 | 146.9 | 51.6 |
| 14300 | 17.9 | 30.9 | 18.5 | 0.0 | 13.6 | 181.4 | 51.5 |
| 14301 | 17.0 | 30.2 | 17.7 | 0.0 | 12.3 | 172.8 | 49.6 |
| 14302 | 15.0 | 30.1 | 18.7 | 0.0 | 12.3 | 138.2 | 47.6 |
| 14303 | 15.4 | 30.9 | 19.0 | 0.0 | 12.6 | 164.2 | 48.2 |
| 14304 | 16.1 | 31.3 | 17.6 | 0.0 | 12.1 | 172.8 | 47.1 |

# BIOGRAPHICAL SKETCH

The author was born in 1989 in Dumre VDC-8, of Udayapur district. He is the youngest son of Mr. Mukunda Prasad Dhakal and Mrs. KalpanaDhakal. He did his School Leaving Certificate (S.L.C.) from Laligurans Secondary English boarding School, Gaighat, Udayapur in 2006 A.D.

He completed his proficiency certificate (+2) from Birat Science Campus, Biratnagar, Morang in 2008 A.D. The author pursued his Bachelor's Degree in Agricultural Science (B. Sc. Ag) with elective Agriculture Economics as elective from Tribhuvan University, Institute of Agriculture and Animal Science, Rampur, Chitwan in 2013. With the aim of specialization in Agronomy, he enrolled in Postgraduate Program (Masters of Science in Agriculture with major in Agronomy) in 2013.

The author has obtained a number of trainings related to his profession and participated in various seminars and workshops. For his thesis research, he was granted financial assistance from CARITAS-Nepal under SAFBIN project.