GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF WHEAT CULTIVARS UNDER STAGGERED PLANTING AND TILLAGE PRACTICES: SIMULATIONS USING CSM-CERES-WHEAT MODEL IN MID-WESTERN HILLS OF NEPAL

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THESIS

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CERTIFICATE

This is to certify that the thesis entitled “**GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF WHEAT CULTIVARS UNDER STAGGERED PLANTING AND TILLAGE PRACTICES: SIMULATIONS USING CSM-CERES-WHEAT MODEL IN MID-WESTERN HILLS OF NEPAL ”** submitted in partial fulfillment of the requirement for the degree of Master of Science in Agriculture with major in Agronomy of postgraduate program, Institute of Agriculture and Animal Sciences, Kirtipur, is record of original research carried out by **MS. SRIJANA MARASINI** Id No. **R-2013-AGR-01M**, under my 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.

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Prof. Narendra Kumar Chaudhary

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The thesis attached hereto, entitled "**GROWTH, PRODUCTIVITY AND CLIMATE CHANGE ASSESSMENTS OF WHEAT CULTIVARS UNDER STAGGERED PLANTING AND TILLAGE PRACTICES: SIMULATIONS USING CSM-CERES-WHEAT MODEL IN MID-WESTERN HILLS OF NEPAL "** prepared and submitted by **MS. Srijana Marasini**, Id No. **R-2013-AGR-01M,** in the partial Fulfillment of the requirement for the degree of Master of Science in Agriculture (Agronomy), is here by accepted.

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DEDICATED TO

MY
BELOVED PARENTS

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Srijana Marasini

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACRONYMS AND ABBREVIATIONS

%	: Percent
@	: At the rate of
^0C	: Degree Centigrade
AGDP	: Agriculture Gross Domestic Product
ANOVA	: Analysis of Variance
ATC	: Agricultural Technology Centre
CC	: Climate Change
CFCs	: Chloro Fluro Carbons
CIMMYT	: International Centre for Maize and Wheat Improvement
cm	: Centimeter
Co_2	: Carbon dioxide
CSM	: Crop Simulation Model
CT	: Conventional Tillage
CV	: Coefficient of Variation
DAP	: Di Ammonium Phosphate
DAS	: Days After Sowing
DF	: Degree of Freedom
DLL	: Drained Lower Limit
DM	: Dry Matter
DMRT	: Duncan’s Multiple Range Test
DSSAT	: Decision Support System for Agro -technology Transfer

DUL	: Drained Upper Limit
et. al.	: et alii (Latin), and others
FYM	: Farm Yard Manure
GCM	: General Circulation Model
GDD	: Growing Degree Days
GHGs	: Green House Gases
gm	: Gram
GSL	: Growing Season Length
ha	: Hactor
HFCs	: Hydro Fluoro Carbons
HI	: Harvest Index
HTU	: Helio-thermal unit
HUE	: Heat Use Efficiency
IAAS	: Institute of Agriculture and Animal Science
IPPC	: International Panel on Climate Change
Kg	: Kilogram
LSD	: Least Significance Difference
M. Sc.	: Master of Science
m.a.s.l.	: meter above sea level
mg	:Milligram
MoAD	: Ministry of Agricultural Development
MOP	: Muriate of Potash
MSTAT	: Michigan University Student’s Statistical Analysis Tool
N	: North
N_2	: Nitrogen

N_2O	: Nitrous Oxide
NARC	: Nepal Agriculture Research Council
$NH_4{}^+$ N	: Ammonical Nitrogen
NMRP	: National Maize Research Program
No.	: Number
$NO_3{}^-$N	: Nitrate Nitrogen
OM	: Organic Matter
P_2O_5	: Potassium Oxide
ppb	: Part Per Billion
ppm	: Part Per Million
PTI	: Pheno thermal index
RMSE	: Root Mean Square Error
RWC	: Rice-Wheat Cropping System
SD	: Sowing Date
SF_6	: Sulphur Hexafluoride
SOC	: Soil Organic Carbon
TGW	: Thousand Grain Weight
ton	: Tonne
wt	: Weight
ZT	: Zero Tillage

ABSTRACT

Name: Srijana Marasini ID No.: R-2013-AGR-01M

Semester and year of admission: First, 2013 Degree: M. Sc. Ag.

Major subject: Agronomy Department: Agronomy

Major Advisor: Prof. Narendra Kumar Chaudhary

A field experiment was conducted to evaluate growth, productivity and agro-climatic indices of wheat cultivars under different tillage and sowings dates and to evaluate CSM-CERES-Wheat model ver.4.5 for assessment of climate change in Dhikurpokhari-3 Kaski, Nepal, during winter season of 2014/15. The experiment was conducted in strip-split plot design in three replications. There were sixteen treatment combinations consisting of two establishment methods; zero tillage and conventional tillage, four wheat varieties; Farmer's Local, WK-1204, Annapurna-4 and Gautam and two sowing dates; November 15 and November 30. Soil of experimental field was sandy loam in texture and slightly acidic in reaction with 0.27% total nitrogen and 45.36 kg/ha P_2O_5 and 221.6 kg/ha K_2O, 3.09% organic carbon in upper surface of soil. Research result revealed that grain yield was significantly affected by tillage, varieties and sowing dates. Grain yield of WK-1204 variety was found significantly higher at both sowing dates (3.39 t ha^{-1} in November 15 and 3.56 t ha^{-1} in November 30) under zero tillage but it was statistically at par with Annapurna-4 (3.31 t ha^{-1}) under zero tillage and November 15 sowing date. Varieties and sowing dates showed significant influence on maturity, heading and anthesis, whereas tillage practices had no significant influence. Phenological duration was longer in WK-1204 followed by Gautam and Annapurna-4 whereas duration was shorter for Farmer's Local. Significantly higher effective tillers and spike weight were observed in zero tillage whereas effective tillers m^{-2} and filled grains $spike^{-1}$ were non-significant due to sowing dates. All the wheat varieties showed higher growing degree days and heat use efficiency on November 15 and lower on November 30. Higher growing degree days and heat use efficiency was found in WK-1204. There was positive correlation of yield with leaf area index, dry matter and effective tillers/m^2 (R^2=0.33, 0.29, 0.44 and 0.38 respectively). CSM-CERES-Wheat model was calibrated, validated and simulated under mid-hill agro-climatic condition of Dhikurpokhari, Kaski District, Nepal. Model calibration was done by using best treatments (Farmer's Local, Annapurna-4, Gautam on Nov 15 and WK-1204 on Nov 30 under zero tillage). Observation on anthesis (RMSE=3.73 d-Stat =0.80) and physiological maturity dates (RMSE=3.189, d-stat=0.92), grain yield (RMSE=779.09, d-stat=0.60), and maximum leaf area index (LAI) (RMSE=2.49, d-stat=0.54) were used for the model validation. The sensitivity analysis on various aspect of wheat showed that model was sensitive to weather year, nitrogen levels and different parameters of climate change. Increase in minimum and maximum temperature by 4^{o}C decreased the wheat yield whereas decrease of temperature by same amount increases the yield in all wheat varieties. The model evaluation showed that CSM-CERES-Wheat can be used preferably in mid-western agro-ecozone of Nepal.

Prof. Narendra Kumar Chaudhary	Srijana Marasini
Major Advisor	Author

सोध-सार

नाम : सृजना मरासिनी
परिचय पत्र नं. : आर-२०१३-एजीआर-०१
एम
सत्र र भर्ना वर्ष : प्रथम, २०७०
उपाधि : कृषि स्नातकोत्तर
मुख्य विषय : बाली विज्ञान
विभाग : बाली विज्ञान
मुख्य सल्लाहकार : प्रा. नरेन्द्र कुमार चौधरी

वि.स. २०७१/०७२ सालको हिउँदको समयमा कास्की जिल्लाको ढिकुरपोखरी गा.बि.स. मा सि.एस.एम.-सेरेस-गहुँ भर्सन ४.५ को गहुँका जातहरुलाई विभिन्न जोताई र लगाउने समय सँग संसर्ग गरि उब्जनी र

उत्पादकत्वमा जलवायु परिवर्तनले पार्ने असर बारे अनुमान गर्न यो अनुसन्धान गरिएको थियो । यो अनुसन्धान स्ट्रिप स्पिलिट प्लट डिजाइनमा ३ पटक पुनराबृत्ति गरी परीक्षण संचालन गरीएको थियो । सोह्र वटा उपचारहरु जसमा चार वटा गहुँका जातहरु (स्थानीय गहुको जात, डब्लु के-१२०४, अन्नपुर्ण-४ र गौतम) साथै २ प्रकारका खनजोत (सुन्य जोताई र परम्परागत जोताई) र २ वटा बिउ छर्ने समयको ससंर्ग गरिएको थियो । परिक्षण गरीएको खेतको माटोको बुनोट बलौटे दोमट र पि.एच. अम्लीय थियो भने नाईट्रोजन, फस्फोरस र पोटास तथा प्राङ्गगारीक कार्बन क्रमशः ०.२७ प्रतिशत, ४५.३६ के.जि. प्रति हे., २२१.६ के.जि. प्रति हे., तथा ३.०९ प्रतिशत रहेको थियो । अनुसन्धानको नतिजा अनुसार उत्पादनमा जोताई, गहुंको जात र बिउ छर्ने समयको असर तथ्यांकीय आधारमा प्रभावकारी पाईएको थियो । सुन्य जोताईमा गहुँको डब्लु के-१२०४ जातको उत्पादन दुबै बिउ छर्ने समयमा (नोभेम्बर १५ मा ३.३९ टन प्रति हे. र नोभेम्बर ३० मा ३.५६ टन प्रति हे.) तथ्यांकीय आधारमा बढी रहेको पाईयो तर शुन्य जोताईमा नोभेम्बर १५ मा छरेको अन्नपुर्ण-४ गहुँको उत्पादन तथ्यांकीय आधारमा समान पाईएको थियो । गहुँको जात र छर्ने समयले गहुंको पाक्ने समय, बाला निस्कने र फूल फुल्ने समयमा असर गरेको पाईयो तर जोताईको कुनै असर नरहेको पाईयो । डब्लु के-१२०४ जातको गहुँमास बै भन्दा बढी फुल फुल्ने अवधि बढी पाईयो र स्थानीय गहुँको जातमा सबै भन्दा कम पाईयो । तथ्यांकीय हिसाबले प्रभावकारी गाँज संख्या प्रति वर्ग मिटर र बालाको तौल सुन्य जोताईमा बढी पाईयो भने छर्ने समयले उक्त कुराहरुमा कुनै प्रभाव नपारेको पाईयो । नोभेम्बर १५ मा छरेका सम्पूर्ण गहुँका जातहरुले ग्रोईङ्ग डिग्री डे र ताप प्रयोग गर्न सक्ने कार्यक्षमता नोभेम्बर ३० मा छरेको भन्दा बढी पाईयो जुन अन्य जातहरु भन्दा डब्लु के-१२०४ जातको गहुंमा बढी पाईयो । उत्पादनको विशेषतामा फरक पार्ने कुराहरु जस्तै एल. ए. आई., सुख्खा पदार्थ, प्रभावकारी गाँज संख्या प्रति वर्ग मिटर र प्रति बाला भरिएको दानाहरुको उत्पादनसंगको अन्तर-सम्बन्ध (क्रमशः आर.=०.३३, ०.२९, ०.४४ र ०.३८) भएको पाइयो । कास्की जिल्लाको अवस्थामा सि.एस.एम.-सेरेस-गहुं मोडलको मुल्याङ्कन गर्न डिस्याट भर्सन ४.५ को प्रयोग गरियो । उत्तम उपचारहरु (स्थानीय जात, अन्नपुर्ण-४, गौतम नोभेम्बर १५ मा शुन्य जोताई र डब्लु के-१२०४ नोभेम्बर ३० शुन्य जोताई) बाट लिइएको जानकारीलाई अवलोकन गर्दै अनुबंशीय कोफिसिएन्टहरु निकालियो । छानिएका कारक तत्वहरु जस्तै फुल फुल्ने दिन(आर. एम्.एस्.इ =३.७३१, डिस्टाट्=०.७९) पाक्ने दिन (आर. एम्.एस्.ई. =३.१८, डिस्टाट्=०.९२) दानाको उत्पादन (आर. एम्.एस्.ई.=७७९.०९, डिस्टाट् =०.६०) र अधिकतम

एल.ए.आई. (आर.एम्.एस्.ई.=२.४८, डिस्टाट्=०.५३) निर्धारण गरि प्रमाणिकरण गरिएको थियो । मोडेल विभिन्न मौसम वर्ष, रोप्ने नाईट्रोजनको मात्रा र जलवायु परिवर्तनमा संवेदनशिल पाइयो । यसैगरी, अधिकतम् र न्यूनतम् तापक्रम ४ डिग्री सेन्टिग्रेडले बढाउदा उत्पादन घटेको पाईयो र त्यही मात्रामा तापक्रम घटाउदा उत्पादन बढेको पाईयो । सि.एस.एम.-सेरेस-गहुं मोडलको नेपालको मध्य पश्चिमी पहाडी भेगमा सहजै प्रयोग गर्न सकिने पाईयो ।

प्रा. नरेन्द्र कुमार चौधरी	सृजना मरासिनी
मुख्य सल्लाहकार	लेखक

1 INTRODUCTION

Wheat (*Triticum aestivum L.*) is the leading cereals in the world, occupying 17% of the total cultivated land area of the world (CIMMYT, 2002). It is the staple food of 35% of the world's population and provides more calories and protein in world's diet than any other cereal (CIMMYT, 2002). Globally it is cultivated in the area of 21.5 million ha with the productivity of 3.11 mt/ha (FAOSTAT, 2015). Wheat is the major cereal crop of Nepal occupying 22% (0.75 million ha) of total area and contributes 20% (1.7 million metric tons) of the total cereal production with productivity of 2.29 t ha^{-1} (MOAD, 2014). Wheat contributes 7.14% in the AGDP share of the country. Mid and high hill represents about 34% total wheat area and contributes about 24% total production of wheat in Nepal (Poudel *et. al.*, 2013).

The per capita wheat consumption has been increased from 17.4 kg in 1972 to 72 kg in 2012 (Poudel *et. al.*, 2013). About 58% of area of wheat crop is grown under rainfed environment (Poudel *et. al.*, 2013). Rice -Wheat system is common in Nepal since ancient time, occupying more than 0.56 million ha of land in the terai and hilly regions (Tripathi *et. al*., 2002). Nearly 84% of the total wheat cultivated is cropped under rice-wheat cropping system (Timsina *et al*., 2001). Sustainability of the system is under threat because of increasing cultivation cost and declining soil fertility (Shah *et al*., 2011). There are several research efforts to lift the rice and wheat yields but there are still large gaps between biologically and climatically achievable potential yields and research station and on farm yields (Timsina and Connor, 2001, Timsina *et al*., 2004).

Wheat in case of Nepal is sown after rice and it grows and survives on the residual soil moisture, late monsoon rains and winter rain (Shrestha *et al*., 2013). Low wheat yield in Nepal is due to late planting of wheat is very common due to an excess or lack of moisture just after rice harvesting, delay in rice harvesting due to late maturing varieties and shortage of labors during rice harvesting time (NWRP, 2011). In late sown wheat high temperature and desiccating winds during the month of April may cause forced maturity resulting reduction in test weight and decrease grain yield (Singh and Dahiwal, 2002). Wheat is grown mostly in conventional tillage system in Nepal. Soil erosion may be increased by conventional tillage there by accelerating the removal of soil organic matter is concentrated in the eroding top soil. The soil resource base has been steadily regarded, especially when tillage is combined with in situ burning of crop residue (Montgomery, 2007). As the Nepalese agriculture is rainfed dominant and rice cultivation is followed by wheat, it faces winter, anthesis and post anthesis drought with high temperature stress during later stage of growth. Moreover, the shift in monsoon rainfall from Jestha-Asar to Shrawan-Bhadra due to climate change has pushed the timely sowing of wheat exposing it to the post-anthesis heat stress (Giri, 1998). Climate influences plant life in many ways and can inhibit, stimulate, alter or modify crop performance (Amgain *et al*., 2006). Climate components like temperature, solar radiation, rainfall, relative humidity and wind velocity independently or in combination, can influence crop growth and productivity (Amgain *et al*., 2006). With the increasing population and purchasing power, demand on food has also increased which is impossible to meet with the present varieties, technologies and management practices. The deterioration of soil health, threats of climate change, emergence of new weeds and diseases, increase on the labor, energy and water intensive wheat cultivation has aggravated the situation.

Conservation agriculture has been regarded as management of soil, water and agricultural resources to achieve economic, ecological and socially sustainable agricultural production (Jat *et al.*, 2012). Furthermore, it increases aeration, mixes plant residue into the soil resulting in faster decomposition and exposure of previously protected organic matter (Blevins and Frye, 1993). It allows timely planting of wheat within short turn–around time and reduction in cost of production (Singh, 2005). Timely planting also saves crop from high temperature, high wind velocity and low humidity at grain filling stage and un- timely rains don’t interfere with harvesting threshing operations (Chaudhary *et al*., 1993). High temperature at the reproductive stage hastens the spike development resulting in abortion of late forming florets and reduction in potential kernel numbers (Moolsrl, 1994; Talukder, 2014). High temperature stress at grain filling stage causes shortening of grain filling period resulting in lower grain weight (Talukder, 2014). Growing of suitable variety at an appropriate time is essential for ensuring optimum productivity (Ram *et al*., 2012).

Decision Support System for Agro technology transfer (DSSAT) software consisting of Crop Simulation Model (CSM)-CERES-Wheat, is one of the highly adopted and well-recognized software in the developing world which can investigate the various management and climate change scenarios and can help to identify the best management practices and factor to close the yield gaps and increase the food security (Amgain and Timsina, 2004). This is process based, management-oriented model that can simulate the growth and development of wheat as affected by varying levels of water, nitrogen and cultivar characteristics (Amgain, 2004). Several studies have done separately in on station of various parts of the world, but there is lack of study focusing the combined tactics of variety, planting date and tillage methods on growth and productivity of wheat in mid-hill conditions of Nepal and this study was proposed, executed and accomplished with dual aims of studying the following broad and specific objectives;

General objective

- To determine strategies for the higher yields of wheat through conservation agriculture, time of sowing, variety selection and residue management.

Specific objectives

- To assess the phenology, growth and productivity of wheat cultivars under different planting and tillage practices in farmer's field.
- To identify the optimum sowing time of wheat at mid-western hills of Nepal under changing climatic scenarios.
- To evaluate the CSM-CERES-Wheat model ver. 4.5 under western-hill condition and its application under different climatic scenarios.

2 LITERATURE REVIEW

2.1 Rice-Wheat cropping system

Rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) system, the practice of growing wheat after rice in an annual rotation, is the leading cereal cropping system in the Indo-Gangetic plains and vital for the food security, livelihood and employment of millions of people in the region (Timsina and Connor, 2001; Gupta *et al.*, 2002). Rice and wheat occupy 1.5 and 0.76 Million ha, respectively and are grown in succession on more than 0.56 Million ha which accounts 37% of the rice and 85 % of wheat area in Nepal (Tripathi *et al*., 2002). It is, one of the principle cropping systems in Terai and mid-hill regions of Nepal, occupies one-fourth of the total cropped area and provides food, income and employment to 83% of the Nepalese population.

It is largely practiced on low land ecosystem where heavier soil texture, excessive soil moisture, and late rice harvest lead to higher production cost and delay in wheat planting. The traditional method of wheat establishment involves excessive tillage which is painstaking, time and energy consuming that further leads to poor plant stand and late planting (Giri, 1997; Hobbs *et al*., 1997; Tripathi, 2002). Residue retention in situ conserves soil moisture enhance soil organic carbon and N efficiency (Hobbs and Gupta 2003).

In order to feed the growing population, the country needs to increase the productivity of crops, while maintaining the sustainability of the cropping system is another challenge. Recent studies indicate a slowdown in the productivity of growth in the rice-wheat systems (Kumar *et al.*, 2002a). Evidence from long-term experiments shows that crop yields are stagnating and sometimes declining (Duxbury *et al.*, 2000; Ladha *et al*., 2003a). The observed yield decline from the long term experiment in rice-wheat system is due to deterioration of soil physical properties and soil fertility (Sharma and Jain, 1997; Ladha *et* *al.*, 2003). In addition, environmental degradation, increasing water scarcity, labor shortage and socioeconomic changes are seen as the other major contributors to the stagnation of rice–wheat productivity in the IGP (Erenstein *et al.*, 2007).

The degraded fertility status of the rice-wheat system in IGP has been declined due to poor soil organic matter content are being consistently depleted of their finite reserve of nutrients by crops (Singh and Singh, 2003). Rao (2015) reported that excessive tillage, imbalance use of chemical fertilizer, removal of crop residue from the field leads to the deterioration of soil organic matter and finally trigger to the soil degradation

2.2 Conventional tillage

Conventional tillage or intensive tillage system includes all tillage practices that leave less than 15% of residues on soil surface. Conventional tillage can be defined as moldboard ploughing followed by disking one or more times to obtain loose, seedbed (Phillips *et al*., 1980). Conventional tillage requires high energy input and also causes water loss and long-term soil physical degradation (Barzeger *et al.*, 2004). It kills weeds competing with crop plants for water and nutrients and modifies the circulation of water and air within the soil which enhances organic matter decomposition and hence the releases of nutrients like nitrogen for crop growth (Reijntjes *et al*., 1992). The traditional method of wheat establishment involves excessive tillage which is painstaking, time and energy consuming that further leads to poor plant stand and late planting (Giri, 1997; Hobbs *et al*., 1997; Tripathi, 2002). Rice straw mulching decreased soil temperature and reduced the weed dry matter, increased yield attributes and yield in wheat (Lawate *et al*., 2015). With tillage, soil is opened up and made loose, and the carbon dioxide is allowed to escape into the atmosphere (Giri, 1997). Globally, agriculture and intensive tillage have caused between 30 to 50% decrease in soil carbon since many soils were brought into cultivation over 100 years ago (Schlesinger, 1985). Plant stover is a major source of C input into the soil system and plays a very vital role as nourishment for the soil microbial population (Reicosky, 1997). The management of crop residues and soil organic matter is of primary importance in maintaining soil fertility and productivity (Reicosky, 1997). Conventional tillage operations pose some serious concerns e.g. high fuel and time requirements, soil compaction and deterioration in soil structure. The high fuel cost necccessitates the use of alternate tillage systems with less chances of erosion (Mitchell *et al*., 2009). In many instances such intensive operations also adversely affect soil structure and causes excessive breakdown of aggregates' leading to either wind or water erosion (Mahboubi *et al*., 1993). Use of intensive and unnecessary conventional tillage practices is often harmful to soil (Ali *et al*, 2013).

2.3 Zero tillage

Zero tillage in rice-wheat systems ranges from surface seeding to planting with seed drills drawn by four-wheel tractors (Hobbs *et al*. 1997). In surface seeding, wheat seeds are broadcast on a saturated soil surface before or after rice harvest (Tripathi *et al*., 2006). The delay of every successive day in planting beyond November third week decreases the grain yield progressively (Ali *et al*., 2010; Irfaq *et al*., 2005; Sharma, 1992). Therefore, to avoid delay in planting and reduce the cost of production, farmers have started adopting resource conserving technologies such as zero tillage and surface seeding in wheat production (Gupta and Seth, 2007). Due to the high cost of fuel and labor associated with conventional tillage, and because of their advantageous environmental consequences, interest in reduced and zero tillage systems has increased (Hannukankanen, *et al*., 2011). Zero tillage (ZT) in combination with a surface crop residue can improve the agronomic water balance by increasing the amount of water that is readily plant available (Sommer *et al*., 2012). Savings in input cost, fuel consumption and irrigation water-use have been reported due to adoption of zero tillage in wheat cultivation (Malik *et* *al*., 2003a; Bhushan *et al*., 2007). Zero tillage compared to conventional tillage may offer many benefits including reduction of soil erosion risk improve soil biological and biochemical properties and reduce in energy inputs (Amato *et al*., 2002).

Zero tillage allows timely planting of wheat. Another benefit of earlier sowing under zero tillage is that *Phalaris minor*, a herbicide-resistant weed in wheat, is less competitive than when wheat is sown late under conventional tillage, and hence wheat growth and yields are improved (Malik *et al.*, 2002, 2003a, b). Wider adoption of zero tillage in wheat was due to a combination of both increased yields and reduced production costs. ZT can save US $40–50/ha compared with CT (Malik *et al.*, 2002). Rice-wheat systems have led to land degradation. Excessive groundwater pumping has led to lowering of the water table in some of the rice- wheat areas (Kataki *et al*. 2001; Malik *et al*. 2002a). Zero tillage potentially reduces irrigation water use alleviating pressure on aquifers. ZT technology generates higher yields at lower production costs and, and it is an environment friendly practice that saves water and soil (Hobbs *et al*., 1997). Zero tillage allows farmer to establish wheat crop almost immediately after rice harvest, thereby improving yields and input use efficiency (Khan *et al*., 2000). Economically zero tillage is superior over conventional method of sowing because more net returns were recorded on zero tillage farms than that of conventional wheat farms (Nagarajan, 2002).

2.3.1 Effect of zero tillage on growth and yield of wheat

Higher crop yields under ZT than under CT are typically obtained in dry climate (Wang *et al*., 2011). Result showed that growth and yield traits for wheat under ZT was higher than the CT in number of grains spike $^{-1}$, grain yield, and straw biomass (Alrijabo and Hassan 2011). Studies have shown that zero tillage (ZT) in combination with a surface crop residue can improve the agronomic water balance by increasing the amount of water that is readily plant available (Sommer *et al*., 2012). Sandeep *et al*. (2012) indicated that adopting a better tillage system not only improves the soil health and crop productivity but also improves the environment. (Maqsood, 1998; Zamir, 2006) working on different tillage systems demonstrated that zero tillage gave maximum plant height. Highest number of fertile tillers (429.66) was counted in Punjab-11 at Zero tillage (Ali *et al*, 2013).

Seed planted under zero tillage had 19% more emergence than that under conventional method and 43% lower weed densities when direct drilling was used in place of conventional method as reported by Aslam *et al.* (1989). Zero tillage technology enhances the wheat yield as compared to the other tillage practices and facilitates less use of machinery and hence energy can be saved through less consumption of fuel (Grey *et al.*, 1996). Zero tillage system performed better as compared to other tillage practice because it is very cheap as output obtained from this system is higher than other tillage systems and also this technology is environment friendly (Nagarjan *et al.*, 2002).

2.3.2 Relationship of zero-tillage with crop yield

Zero-tillage practice in wheat offers significant role in increasing cropping intensity and yield. Studies have shown that it is possible to sow wheat about 15-20 days earlier than that of the conventional practice through zero-tillage (Ladha *et al.*, 2003; Regmi *et al.*, 2009). As a result, wheat can be harvested earlier and it is possible to grow spring season crops such as maize, mungbean and so on. Timely planting of wheat (October 15th to November 15th as per recommended by Nepal Agriculture Research Council) is also important to escape the problem of terminal drought that causes sterility problem in wheat. Studies have confirmed that planting of wheat after first week of December reduces the wheat yield @1-1.5% per day (Gupta and Sayre, 2007; Ladha *et al.*, 2003). Regmi *et al.* (2009) found 30-40% higher yield in zero-tillage practice as compared to conventional practice in Terai areas of Nepal. Similarly, Shah *et al* (2011) found 16% higher wheat grain yield in zero-tillage (1.8 t ha^{-1}) than that of conventional tillage (1.58 t ha^{-1}). The long-term experiments carried out India and Pakistan from 1985 to 2003 show 30-50 % higher grain yield of wheat in zero-tillage as compared to the conventional one (IFPRI, 2009). Hobbs and Gupta (2003) found that yield of wheat increased by 41% in zero tilled plots in comparison to normal tilled plot mainly due to an average 24 days early planting in zero-till.

2.3.3 Impact of zero tillage on economics of wheat production

The net income is higher in ZT method due to higher yield and lower cost of cultivation as compared to CT method of wheat cultivation (Tripathi *et al*., 2013). Research results showed that farmers saved 6.68% human labor, 46.3 % machine labor and 17.65% irrigation water in ZT compared to CT (Tripathi *et al*., 2013).

By adopting zero tillage method, farmers can save a substantial quantity of resources which helps to overcome the problems of human and machine (tractor) labor shortage at the time of land preparation and sowing operations (Tripathi *et al.,* 2013). Several studies have also shown that ZT method of wheat production provides several benefits such as saving of irrigation water, reduction in production cost, less requirement of labor and timely establishment of crops, resulting in improved crop yield and higher net income (Laxmi *et al*., 2007; Farooq *et al*., 2006; Erenstein *et al*., 2007). Farmers are more interested towards ZT method over CT due to better seed germination and yield of wheat (Tripathi *et al.,* 2013). It has been observed that among the integrated conservation and resource management technologies, ZT for wheat was most successful in terms of crop establishment and gain in yield ranging from 1 to 12% (Erenstein and Laxmi, 2008).

2.4 Effect of zero tillage on soil properties

Zero tillage typically improves soil quality in various dimensions, including soil structure, soil fertility, and soil biological properties. Study found that converting from conventional plowing to conservation tillage resulted in a 56 % increase in soil organic carbon over a ten year period (Lal et al., 1998). Better aggregation (Lal *et al*., 1994) and improved pore size distribution (Bhattacharyya *et al*., 2006a) was observed by the adoption of zero tillage. Zero tillage achieved 28% increase in plant available soil water at sowing as compared to conventional tillage and an associated increase of 1.2 t/ha/year wheat grain (Mc Garry *et al*., 2000).

Studies have also reported that the upper soil surface for ZT was comparatively soft and had higher moisture content and that there was no significant difference in bulk density under both tillage systems (Kumar *et al*., 2002b; Malik *et al*., 2002c; Yadav *et al*., 2002a). The ZT soils reportedly have higher organic carbon contents than CT soils but they also have a lower pH due to nitrification (Chauhan *et al*., 2002).

Residue mulch or partial incorporation in soil by conservation tillage has also been shown to increase the infiltration by reducing surface sealing and decreasing runoff velocity (Box *et al*., 1996). Higher soil organic carbon sequestration was observed by adopting zero tillage (Dick *et* al., 1991 and Panday *et al*., 2008). Surface residues maintained under ZT systems moderate temperature and moisture fluctuations and thus reduce both evaporation and runoff (Blevins and Frye, 1993).

2.5 Effect of sowing date on wheat

The optimum sowing date for wheat irrespective of varieties was observed from November 15 to December 5. However, with minimum yield loss it could be sown up to December 20. Delay sowing resulted in poor grain production (NARC, 2002).The variation in sowing date plays an important role in the variation of wheat yield per unit area (Nasser, 2009). In rice growing regions where wheat follows rice, its sowing usually gets delayed. In the rice-wheat zone people prefer to grow long duration and late maturing rice variety, ultimately causes delay in sowing of wheat. Late planting of wheat after mid November caused significant yield losses. Hence, it necessitates avoiding late sowing of wheat. For in time wheat sowing operations, zero tillage technology is being introduced in Rice-Wheat system (Tahir *et al*., 2008). Under rainfed conditions the sowing date varies in the different locations and depends on rainfall pattern (frequency, duration and amount) as well as the maturity period of the specific wheat variety (Tanner *et al*., 1991).

Thorne (1962) reported that early sowing increases dry matter production, leaf area, number of shoots and amount of nitrogen taken up by the crop. Early sowing appears to result in a long delay in ear initiation and, therefore, favors the formation of greater numbers of leaves on the main shoot (Kirby, 1969). Ibrahim (1996) showed that delayed wheat sowing is often associated with substantial losses in grain yield up to 86%. Due to delay in sowing till 5th December, yield loss of 42% has been recorded (Subhan *et al*., 2004a). As sowing of wheat is delayed, soil temperature decreases which has detrimental effect on seed germination (Gardner *et. al*., 1985) and thereby tillering capacity and number of productive tillers (Shah and Akmal, 2002). The late sown crop matures also in shorter time as compared with the normal sown crop as the hot summer approaches. Thus the late-sown crop takes less number of growing degree days (GDD) due to which yield components decrease and hence the economic yield of the crop suffers negatively (Lone *et al*., 1999).

2.5.1 Effects of sowing date on yield and yield attribute

The highest value for plant height, numbers of tillers m^{-2}, number of grain spike^{-1}, 1000 grain weight, biological and grain yields were produced when wheat was shown on

15th November. But the highest number of non effective tillers m^{-2} and highest straw yield were recorded from sowing wheat on 30th November (Mahfouz, 1992). Early planted wheat yielded maximum grain per spike (44.14), plant height (79.81cm), 1000 grain weight (39.17g), grain yield (4165.7kg/ha) and straw yield (6814.2kg/ha) (Qasim *et al*., 2008). Malik *et al*. (2009) reported that delayed sowing decreased grain yield due to decrease in germination count m^{-2}, number of grains $spike^{-1}$ and 1000-grain weight. It has been observed that early sowing gives high yield than late sowing due to longer growing period (Munir *et al*., 2002; Tanveer *et al*., 2003) and vigorous growth associated with rapid and uniform seedling emergence (Kirby, 1993) and better combination of leaf size and tiller numbers (Regan *et al*., 1992). Lower grain yield was obtained in delay sown wheat due to shorter duration of growth and development (Shahzad *et al*., 2007).

2.5.2 Effective tillers per m^2

Late sowing of wheat tends to reduce number of effective tillers m^{-2} (Malik *et al*., 2009). The maximum number of tillers m^{-2} (285.8) was recorded when wheat was sown on 30th November, where as minimum number of tillers m^{-2} (120.9) was noted when wheat was sown on 15th December (Malik *et al*., 2009). Gul *et al* (2012) reported the significantly higher number of effective tillers m^{-2} (345.61 and 324.77) were obtained in early (Oct 25) and normal (Nov 13) sowing as compared to delay sowing (Dec 23). Nasser (2009) reported highest number of effective tillers (435.8 and 420.0) and spikes (413.5 and 402.6)/m^2 were obtained when wheat was sown in mid November. The highest number of non-effective tillers was recorded when wheat was sown in November 30 (Mahfouz, 1992).

2.5.3 Effects of sowing date on spike length

Average spike length was found maximum (10.7 cm) for the Oct.25th sown crop and minimum value of (8.8 cm) when sowing was done on Dec.5th. Decrease in spike length ranged from 10.8% to 24.4% when sowing was done on 5th Dec. as compared with Oct. 25th (Inamullah, *et al*., 2007). The spike length probably decreased due to delay in sowing because of the sensitivity of the wheat plants to photoperiod and temperature (Slafer and Whitechurch, 2001). Maximum spike length of 10 cm was recorded in plots which were sown on 16th January (Shah *et al*., 2006).

Spike length were obtained significantly higher in Nov1st sowing (10.60 cm) compared to sowing Nov 30th (9.50) but statistically at par with Nov 15 sowing (10.60 cm) in the year 2006/07. But in the year 2007/08 spike length were not influenced significantly by the different sowing date November 1, November 15 and November 30) (Gizawy, 2009).

2.5.4 Grains per spike

Wheat sown on November 15 gave maximum number of grain per spike (44.14) as compared to November 30 (38.98). Maximum number of grains spike $^{-1}$ (40.44) was noted when wheat crop was sown on November 15th, whereas minimum number of grains spike $^{-1}$ (31.89) was counted when crop was sown on 15th December (Malik *et al*., 2009). Significantly higher number of grains spike^{-1} (58.6) were recorded when planting was done on Oct. 25th, compared to Nov. 5th (55.6), Nov 15th (47.4), and Nov 25th (47.1) and Dec 5th (44) (Inamullah *et al*., 2007). Grains spike^{-1} was significantly higher at Nov 15 planting (53.99) as compared to Dec 15 planting which produce the lowest grains spike^{-1} (Said *et al*., 2012).

Early sowing date produced significantly more number of grains spike^{-1} (48.22). Oct. 25th sowing produced higher grains spike^{-1} (56.71) as compared to delayed sowing Dec 23th (36.89) (Yajam and Madani, 2013). Malik *et al* (2009) reported that Nov 25th sowing of wheat produces significantly higher grain spike^{-1} as compared to Nov 30th (37.89) and Dec 15th (31.89).

2.5.5 Thousand grain weight

Thousands grain weight decreased due to delay planting of wheat. Late planted wheat produced minimum 1000-grain weight as compared to early and mid dates (Qasim *et al*., 2008). Delay sowing shortens the duration of each development phase which ultimately reduces grain filling period and lowers the grain weight (Spink *et al*., 2000). 10th November showing produced heavier, thousand grain weights (43g) than late planting 10th January (Anwar *et al*., 2015). The highest 1000 grain weight was noted in November as compared to December sowing (Malik *et al*., 2009).

The 1000-grains weight decreased due to delay in sowing because the wheat plants may not have got sufficient time to increase the grain size sufficiently because of longer photoperiod and higher temperature (Slafer and Whitechurch, 2001). The highest thousand grain weight was produced in early sowing October 25th (43.1g) and lowest was recorded in December 5th (34.6) (Inamullah *et.al*., 2007).

The highest 1000 grain weight among the sowing dates was obtained at 1st November in both seasons and delay in date of sowings reduced the 1000 grain weight that could be attributed to shorter grain filling period (Suleiman *et al*., 2014). The crop sown on 23th September produced significantly heavier test weight (48.18g). The minimum 1000 grain weight (41.11) was produced on December 10. The grain weight decreased significantly with each 15days delay in sowing (Yajam and Madani, 2013).Among different sowing dates, the maximum test weight (40.1 and 40.0 g) was recorded on October 25th and November 10th, respectively whereas minimum (36.1 g) was noted on December 25th sowing date (Baloch *et al*., 2010).

2.5.6 Grain yield

Darwinkel *et al*. (1977) reported that the delay sowing date is one of the main reasons for reducing wheat yield. Shahzad *et al*. (2007) also obtained lower grain yield with delay in sowing due to shorter duration of growth and development. The grain and biomass yield of all wheat cultivars were higher at November 30 sowing as compared to early and late sowing at Khumaltar (NARC, 2002).

Kumar *et al.* (2000) reported better grain yield in 20th November sowing than 1st November or 10th December sowings. Yield reduction of 27 and 52% was noted by Iqbal *et al.* (2002) when wheat crop was sown on December 15 and 31, respectively. Akhtar *et al.* (2006) concluded that regardless of varieties/cultivars, better yields were obtained when wheat was sown after 15th and before 30th November.

2.5.7 Straw yield

Early sowing produces higher straw yield (Anwar *et al.*, 2015). The Straw yield was significantly highest in residue retained treatment under no-tillage compared to tillage treatment (Mohammed *et al*., 2003). Maximum straw yield was recorded in November 15th (6814kg/ha) sowing as compared to November 30th (6436 kg/ha) and December 15th (4979kg/ha) sowing (Qasim *et al.*, 2008).

2.6 Climate change

A Climate Change (CC) refers to a change in the state of the climate that can be identified by changes in the mean or variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2007a). Natural variability or human induced increase in greenhouse gases (GHGs) is the main factors responsible for CC. Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and F-gases such as per fluorocarbons (PFCs), hydro fluorocarbons (HFCs), sulphur hexafluoride (SF_6), and chlorofluorocarbons (CFCs) are the most prominent GHGs that trap heat and cause

CC (IPCC, 2007b). Fuel combustion, deforestation, transportation, agriculture, urbanization, and industrialization are the main sources of GHGs emission. Marked increase in the concentration of CO_2 from about 280 ppm in pre-industrial value to 379 ppm in 2005 has been reported. Similarly, during the same time period concentration of CH_4 and N_2O has increased from 715 ppb to 1774 ppb and 270 ppb to 319ppb, respectively. Total CO_2 equivalent of prominent GHGs is estimated to be around 455 ppm, which if not stabilized below 550 ppm CO_2eq would lead to the most harmful irreversible consequence of CC through temperature rise more than 2^oC (IPCC, 2007a). According to (IPCC, 2007), there has been an unprecedented warming trend during the 20th century. The current average global surface temperature of 15ºC is nearly 0.6ºC higher than it was 100 years ago-most of the increase has been the consequence of human activity. A further increase of 1.5-6 ºC is projected for the period to 2100. Fourth Assessment Report of IPCC (2007) concluded that “most of the observed increase in anthropogenic greenhouse gas concentrations”. The average atmospheric co_2 concentration has increased from 280 ppm in 1850 to 365 ppm at present, and could exceed 700 ppm by the end of the present century if emissions continue to rise at current rates (IPCC, 2007). Clear indication of CC in the earth has been reported. Over the last few decades, temperature of earth surface has been rising and predicted to rise further if proper attention is not paid. This has caused changes in weather patterns, rise in sea level, and melting of glaciers. In addition, more frequent storm events, increased events of drought, increased number of El-Nino and other adverse climatic situations can also be attributed to the global CC. Prediction shows that rise in 2^oC temperature is inevitable even if emissions are reduced to less than 50% of the current level by 2050. This increase in temperature was determined to be an upper limit beyond which the risks of great damage to ecosystems, and of non-linear responses, are expected to increase rapidly. However, the current trend of emission i.e., emission well above 2000 levels in 2100, would lead to 4^{o}C increase in temperature causing unavoidable devastating losses and excessively higher adaptation costs (IPCC, 2007b). It is expected that up to 2100 that the concentration would become 3 times as much as the pre-industrial time causing 3 to 10^{o}C hikes in temperature (Tisdell, 2008).

2.6.1 Climate change in Nepal

Although Nepal is responsible for only about 0.025% of total annual greenhouse gas emissions of the world (Karki, 2007) and is experiencing the increasing trends and the associated effects of climate warming. Per capita CO_2 from fuel combustion in 1997 for Nepal was 0.11 ton, which is very low compared to neighboring countries like India (1.2), China (3.8) and Bangladesh (0.25) and negligible compared to that of United States of America (20.38) and Japan (9.84) (Malla, 2007).

2.6.1.1 Change in Precipitation

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 east to less than 250 mm in the North West (Rai, 2007). 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 (Regmi, 2007). Rainfall was recorded minimum in the year 1972, 1977, 1992 and 2005 and maximum in the year 1975, 1985 and 1998, respectively (Malla, 2009). Traditional rainfalls of Jestha and Ashar (mid July) have been shifted in Shrawan and Bhadra in Kathmandu and it has affected negatively in the rice production (Dahal, 2009). There will be increase in dry period, intense rainfall, flood, landslides, forest fires and glacial retreats threats due to climate change (Shrestha, 2007). Erratic rainfall events (i.e. higher intensity of rains but less number of rainy days and unusual rain) with no decrease in total amount of annual precipitation have been experienced. Such events increase possibility of climatic extremes like irregular monsoon pattern, droughts and floods. For example, there were rain deficit in eastern terai and western regions, normal rain in far western region and heavy rain in the mid western region creating flood, landslide and inundation. People in Nepal are experiencing more intensive rainfall and subsequent flood and landslide that have direct adverse impact on livelihood assets such as physical, natural, financial, social, and human (Vidal, 2006; Gautam *et al*., 2007a; Gautam *et al*., 2007b; Pokhrel, 2007).

2.6.1.2 Change in temperature

In Nepal average temperature increase was recorded as 0.06º per year and that in Terai and Himalayas was 0.04ºC and 0.08 ºC /year respectively (Shrestha, 2007). Nepal has experienced the fastest long-term increase in temperature with 1.6^{o}C increase between 1976 and 2005, which is very high compared to global temperature increase of 0.6^{o}C in the last three decades (IPCC, 2007b). 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.

Agrawala *et al* (2003) reported that temperature increase faster at higher altitudes than at lower altitudes. Due to the change in climate, soil quality is declining due to increased precipitation and occurrences of intense rainfall leading to higher levels of erosion and sedimentation of fertile land. Temperature is rising at an average of 0.4° C per decade, hence affecting soil moisture because of increased evapo-transpiration. Rainy days are decreasing at a rate of 0.8 days per year (Regmi and Adhikari, 2007) leading to a delay in monsoon season and scarcity of water which in turn is causing a change in cropping patterns and crop maturity periods (Regmi and Adhikari, 2007). Additionally high humidity provides a conductive environment for breeding of insects, bacteria and fungi leading to the rise of tropical diseases and also crop destroying pests become more prevalent (Regmi and Adhikari, 2007).

Developing countries are more vulnerable to the effects of climate change due to its high dependence on climate-sensitive sectors like glaciers, agriculture and forestry, and its low financial adaptive capacity (Karki, 2007). 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.

2.6.2 Evidences of climate change in Nepal and Nepalese agriculture

2.6.2.1 General

- Twelve warmest years since 1975 to 2007 (eg. 2006 was the warmest year)
- Late or pre-monsoon, unusual precipitation, decreased rainy days and intense rainfall events caused more runoff and low groundwater recharge.
- Extreme fog conditions have recently been observed in the terai regions.
- Traditional rainfalls of Jestha and Ashar (mid July) have been shifted in Shrawan and Bhadra in Kathmandu. It has affected negatively in the paddy production.
- Receding snowfall and retreating of the glaciers (small glacier mountain shrinking at alarming rate) due to increase in atmospheric temperature in mountain environment.
- Frost day is decreasing in Kathmandu Valley, winter cold shifted to a month later than regular and Snow fall in Kathmandu (Feb 2007, after 60 years).
- Recently Darchula district of the country faced unusual snow fall affecting collection of precious medicinal herbs Yarsa gumba.
- Mosquito from Terai and mid-hill being able to survive in high-hills (Ilam, Helambu area).

2.6.2.1 Agriculture

- Eastern Terai faced rain deficit in the year 2005/06 by early monsoon and crop production reduced by 12.5% on national basis. Nearly 10% of agri-land were left fallow due to rain deficit but mid western Terai faced heavy rain with floods, which reduced production by 30% in the year (Regmi, 2007).
- Early maturity of the crops due to increase in temperature may help to have more crops in the same crop cycle (NARC, 2002).
- Shifting of climatic zones has been observed in the country. Extinction of natural vegetation: local basmati rice varieties, some local wheat, maize and other agricultural crops was also observed.
- Cold wave in Nepal in 1997/98 had negative impacts on agricultural productivity and showed reduction in the production of crops by 27.8, 36.5, 11.2, 30, 37.6 and 38 % in potato, toria, sarson, rayo, lentil and chickpea respectively (NARC, 1997).

2.6.3 Effects of climate change in agriculture

Weather and climate are the key factors affecting the agricultural productivity. Being open to vagaries of nature, agriculture sector is highly vulnerable to climate change phenomena (Ahmed, *et al*, 2012). Change in water availability to crops may be attributed to annual rise of 0.3°C in world average temperature, which would lead to limit cereal production (Schneider, 2007). 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). Hence, plant growth and productivity is severely affected by nature in the form of biotic and abiotic stresses like water stress therefore, physiological and morphological changes in plants needs to be addressed as mitigation approach (Jaleel *et al.,* 2009). Stresses (water and 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).

The impacts on agriculture are the decrease of productive land in some region and increase in other region. So, it is a complex problem to the world (Pathak, 2003a). Rising CO_2 promotes plant growth and if the CO_2 gas doubles, yields will increase by 40%. CO_2 is regarded as the driving factor of climate change, however its direct effect on plant is positive (Warrick, 1988).

Changes in precipitation patterns i.e. intensive rain concentrated in particular month have a devastating effects on crop production (Adams *et al*., 1995). Nepalese agriculture is predominantly rain-fed agriculture. Therefore, any variations in rainfall patterns will have direct impact on Nepalese agriculture. For instance drought condition will result in decreased crop yields thereby total production (Malla, 2007).

Increase in temperature under increased availability of atmospheric CO_2 leads to vigorous growth of food crops and reduce the level of soil organic carbon, soil micronutrient, and enhance decomposition by activating the microbial population in the soil, thereby decreasing agricultural productivity in a long run (Malla, 2003). With the increase in temperature shifting upward of several domestic and wild plants and animals species have been reported in Nepal (Malla, 2007). In general temperature increase will reduce yield and quality of food crops there by exacerbating vulnerability in food supply.

2.6.4 Effects on wheat production

Climate influences plant life in many ways and can inhibit, stimulate, alter or modify crop performance (Amgain *et al*., 2006). It's components like temperature, solar radiation, rainfall, relative humidity and wind velocity independently or in combination, can influence crop growth and productivity. Climatic parameters like rain and temperature strongly affect the growth and productivity of wheat. An experiment conducted in open top chamber at Khumaltar showed the increase of wheat yield by 8.63 and 9.74% even at the increase of the temperature by 6.94^{o}C and the doubling of CO_2 (Malla, 2007). Wheat production was increased by 41.5% in the Terai plain, 24.4% in the hill and 21.2% in the mountain under the elevated CO_2. The yield however decreased by 1.8% in the Terai but continued to increase by 5.3% in the hill and 33.3% in the mountain at 4^{o} C rise in temperature under irrigated condition (Malla, 2007). All over the world concerns now exists about the possible climate change caused by an increase in the concentration of the green house gases such as CO_2, CH_4 and N_2O in the atmosphere (Watson *et al*., 1996). Using general circulation model (GCM), it has been predicted that a doubling of the current CO_2 levels in the atmosphere will cause an increase of 1.5 to 4^{o}C in average global surface air temperature, with accompanying changes in rainfall pattern by the end of the 21st century (Cohen, 1990; Adams *et al*., 1995). Warrick (1988) investigated that at higher level of CO_2 in the atmosphere, C_3 crops specially wheat would show improvement in water use efficiency through less transpiration, in such case at $2{\times}CO_2$ concentration level (680 ppm), wheat production would be increased 10 percent to 50 percent for mid and high latitude region of Europe and America. However, 2^{o}C increase in temperature would decrease the production by 3 to 17 % which might be offset by higher level of precipitation. For each degree centigrade increase in temperature would cause to shift the geographical location for crops production to several hundred kilometers towards mid and high latitude Warrick (1988).

2.7 Decision Support System for Agro -technology Transfer (DSSAT) and crop simulation model (CSM-CERES-wheat)

Rice and wheat are the two most important cereals in Asia and Rice-Wheat (RW) systems are of immense importance for food security in South Asia and China, providing 85% of the total cereal production and 60% of the total calorie intake in India (Amgain, 2006). Being such important crops, there is still gaps in yield (Timsina and Connor, 2001, Timsina *et al*., 2004). The major factor affecting wheat growth and yield is increase in temperature (Qureshi and Iglesias, 1994).

The Decision Support System for Agro-technology Transfer (DSSAT4.5) is a comprehensive decision support system (Tsuji *et al*., 1998; Hoogenboom *et al.*, 2010) that includes the Cropping System Model (CSM)-CERES-Wheat model (Ritchie and Otter-Nacke, 1985). The CSM-CERES-Wheat model can be used to simulate the growth and development of dry land and irrigated wheat across a range of latitudes in northern and southern hemispheres (Jones *et al*., 2003; Hoogenboom *et al.*, 2010). The model has been evaluated and applied to a range of tropical (Timsina *et al*., 1995), subtropical (Hundal and Kaur, 1997; Heng *et al*., 2000) and temperate environments of Asia (Timsina and Humphreys, 2006; Zhang *et al*., 2013). The Decision Support System for Agro-technology Transfer (DSSAT) has been in use for the last 15 years by researchers worldwide. Crop growth simulation models (CSM) provide the means to quantify the effects of climate, soil and management on crop growth, productivity and sustainability of agricultural systems (Amgain, 2004). They can potentially provide a scientific approach to study the impact of current and future climate change on agricultural production (Adams *et al*., 1995). CSM-CERES-Rice and CSM-CERES-Wheat models are process based, management oriented models that can simulate the growth and development of rice and wheat 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 radiations. These models have been validated and tested across the world, including many countries in Asia (Timsina and Humphereys, 2006) 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. Crop production system analysis is necessary to identify tillage and residue management practices that affect crop production. Crop production system is influenced by a complex array of factors combining crop, soil water, climate, and management parameters. Although many critical cropping system factors cannot readily be changed, soil and water conditions are greatly influenced by management and cultural practices that are controllable. Tillage is one management tool under direct human control that is used to modify the crop environment (Davidoff, 1992). Tillage practices have been devised through trial and error to provide better soil conditions for seed germination and crop development and growth. Because of the complex interactions among system components, systems analysis is a useful technique for defining cultural practices that optimize crop production strategies (Davidoff, 1992). Conventionally tillage winter grown wheat (*Triticum aestivum* L.)-fallow system is often water-use inefficient as its fallow phase has frequently less storage efficiency than no-till and organic production practices.

Wheat production is constrained by heat stress for late sowing dates. For optimization of yield, sowing at the appropriate time to fit the cultivar maturity length and growing season is critical (Andarzian *et al*., 2014). Crop models could be used to determine optimum sowing window for a locality. Research result of simulations showed that the yield of early sowing dates (before 15 November) is lower than the yield of normal sowing date (e.g. 15 November) of decreasing crop growth cycle particularly the time from sowing to the anthesis stage (Andarzian *et al*., 2014). The delay in sowing date not only affects yield, but it affects the yield components and other aspects of the growth and development of wheat. It has been reported that decreasing duration of the stem elongation phase (end of tillering to anthesis stages) would result in a lower number of fertile florets (Slafer *et. al*., 2001).

3.7 Agro climatic indices

Temperature is an important environmental factor influencing the growth and development of crop plants. During growth and development of a cereal crop several growth stages are distinguishable in which important physiological processes occur. Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units system (Chakravarty and Sastry, 1984, Rajput *et al*. 1987 and Bishnoi *et al*., 1995).

Plants have a definite temperature requirement before they attain certain phenological stages. To forecast the phenology and crop production attributes for large areas, there is need to develop crop model (Doraiswamy and Thompson, 1982). The heat unit system was adopted for determining the maturity dates of different crops (Bierhuizen, 1973). The accurate prediction develops on the assessment of plant development rate at each growth stage during the growing season. However, the phenology and ambient temperature interaction in wheat under late sowing high temperature growing condition is very important in Bangladesh. Because in Bangladesh 60% of wheat areas are planted late due to various reasons and the crop faces high temperature during reproductive stages (Badaruddin *et al*., 1994). The various measurements of accumulated heat units were calculated according to the following formulae of Rajput (1980).

1. Growing degree days (GDD) = ∑ [(T max + T min)/2 -T b] (T_b = Base temperature= 4.5 for wheat)
2. Helio-thermal unit (HTU) = GDD × Duration of sunshine hour
3. Heat use efficiency (HUE) = Grain yield (kg/ha) ÷ GDD
4. Phenothermal index (PTI) = GDD ÷ Growth days.

3 MATERIALS AND METHODS

The details of the experiment methods adopted and materials executed during the course of experimentation have been described in this chapter under the following headings.

3.1 Description of the experimental site

3.1.1 Geographical location

The experiment was carried out in Farmer's field of Kaski District. The experiment was conducted during November 2014 to April 2015. This location is situated at 28° 1' north latitude and 82° 5' east longitude with elevation of 1280 m masl (Giri and Chalise, 2008). This location falls in mid-hill region of western development region of Nepal.

Figure 1. Location of research site

3.1.2 Cropping history

The research site was followed by Rice-fallow-maize system before the start of the present investigation.

3.1.3 Soil analysis

Soil samples were taken randomly from each replication before sowing of wheat at a depth of 1 m to record the initial physio-chemical properties of the soil. Composite soil sample of 500g was taken and were air dried ground and sieved through 2 mm sieve and subjected to their properties analysis. Soil samples were analyzed at Agriculture Technology Centre (ATC), Pulchowk, Lalitpur, Nepal.

3.1.4 Methods of laboratory analysis

Table1. Methods of laboratory analysis

Parameters	Analysis method
Soil texture	Hydrometer method (Gee and Bauder, 1986)
Soil pH	Beckman electrode pH meter (Cottenie *et al*., 1982)
Soil organic matter	Graham's colorometric method (Graham, 1948)
Soil total nitrogen	Kjeldahl distillation (Bremner, 1982)
Soil available phosphorous	Modified Olsen's (Olsen *et al.*, 1982)
Soil exchangeable	Ammonium acetate extraction method (Pratt, 1965)
potassium	Flame photometry
Soil moisture	Gravemetric method

Table 2. Mechanical properties of soil of experimental site during 2014/015 at Dhikurpokhari, Kaski

Soil depth (cm)	Sand%	Silt%	Clay%	Texture
0-20	48.4	47.9	3.7	Sandy loam
20-40	40.0	48.7	11.3	Loam
40-60	41.0	49.6	9.4	Loam
60-80	37.6	49.0	13.4	Loam
80-100	42.8	44.9	12.3	Loam

3.1.5 Physical analysis

The physical properties of soil especially soil moisture gradient and bulk density at various profiles were determined. The results are presented in Table 3. Drained upper limit (DUL) and drained lower limit (DLL) values were automatically calculated by using CSM-CERES-Wheat (DSSAT ver. 4.5) model. DUL and DLL were known as the highest and lowest field measure water content of the soil after it had been thoroughly wetted and allowed to drain until drainage became practically negligible.

Table 3. Physical analysis of soil of experimental site during 2014/15 at Dhikurpokhari, Kaski

Soil depths (cm)	*Drained upper limit (DUL) in bars*	*Drained lower limit (DLL) in bars*	*Bulk density (Db) (g cm^{-3})*	*Soil moisture content at saturation (bars)*
0-20 cm	0.333	0.129	1.480	0.424
20-40 cm	0.312	0.132	1.360	0.458
40-60 cm	0.296	0.118	1.370	0.493
60-80 cm	0.306	0.133	1.450	0.458
80-100 cm	0.284	0.123	1.530	0.424

3.1.6 Chemical analysis

Soil pH 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 up to 100 cm, pH was increasing. But at 100 cm depth pH was neutral. Total nitrogen was found higher at upper soil profile but found medium in amount with increasing the depth. Available phosphorous content in the experimental field was found medium at 20-40 cm depth but found lower at 20-40 cm. At 40-60 cm available phosphorous content was medium. With increasing depth up to 100 cm depth, it was lower. Soil available potash was found medium in amount at all soil profile. Soil OM was found high in upper profile, while it was medium up to 80 cm and from 80-100 cm depth it was lower.

Table 4. Chemical properties of soil of experimental site during 2014/015 at Dhikurpokhari, Kaski

Soil depths (cm)	Soil PH	NH_4^+ N (%)	NO_3-N (%)	Total Nitrogen (%)	Available P_2O_5 (Kg/ha)	Available K_2O (Kg/ha)	Organic Carbon (%)
0-20	6.18	0.08	0.19	0.27	45.36	221.60	3.09
20-40	6.45	0.03	0.13	0.15	26.35	194.13	1.82
40-60	6.42	0.05	0.09	0.15	32.27	209.73	1.67
60-80	6.80	0.03	0.08	0.12	25.07	192.07	1.47
80-100	7.00	0.02	0.07	0.11	21.31	201.00	1.32

3.1.7 Climatic conditions during experimental period

The experimental site lies in the humid sub-tropical climatic zones of Nepal. The temperature is moderate, with maximum temperature peaks at 24.4^oC in April and falls to minimum of -3.4^oC in January. It is characterized by three distinct seasons namely rainy monsoon (June to October), cool winter (November to February) and hot spring (May to June). Average maximum temperature during the cropping period ranged from 12.25^oC to 20.11^oC. Similarly average minimum temperature during cropping period ranged from 0.59^oC to 8.47^oC. Rainy season starts from mid June and lasts up to mid September. Winter season generally remains dry with occasional rainfall. Total rainfall received during the cropping period was 328.4mm. The maximum relative humidity for the cropping period was during the month of March (60.31%) and minimum was during the month of December (46.85%).

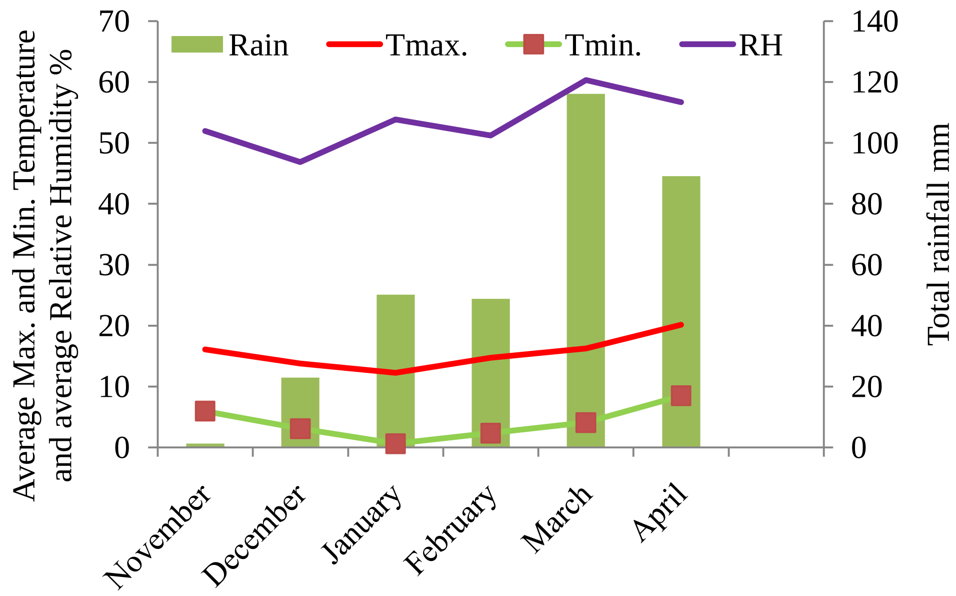

Figure 2.Weather condition during the course of experimentation at Dhikur Pokhari, Kaski, Nepal (November 2014-May 2015) (**Source**: Nasapower, 2015)

3.2 Experimental details

3.2.1 Field layout

The experiment was carried out in strip-split plot design with three replications and sixteen combinations. The treatment consists of combination of the row factor [(two establishment methods: (zero tillage with straw mulch @5ton/ha and conventional tillage without straw mulch)] and column factor [four wheat varieties; (Farmer's Local, WK-1204, Annapurna-4 and Gautam)] and sub plot factor [two sowing dates; (Nov 15 and Nov 30)]

3.2.2 Individual plot layout

The individual plot size was 4.0m×3.0m with row spacing of 20 cm comprising the total number of 12 rows where 3 rows were considered as border rows, 2 rows at one side as sampling rows and rest of the 7 rows as net plot rows (Figure 3).

3.2.3 Treatment detail

Row factor (Establishment method)

T1: Zero tillage with straw mulch @ 5 ton/ha

T2: Conventional tillage without straw mulch

Column factor (wheat varieties)

V1: Farmers Local

V2: WK-1204

V3: Annapurna-4

V4: Gautam

Sub- plot factor (Sowing Date)

D1: November 15

D2: November 30

Table 5. Details of the experimental treatments and their symbols of wheat experiment at Dhikurpokhari, Kaski, Nepal, 2014/2015.

Treatment	Tillage	Varieties	Sowing date	Symbol
T_1	Zero till with straw mulch @5t/ha (T_1)	Farmer's Local (V_1)	Nov 15 D_1	$T_1V_1D_1$
T_2	Zero till with straw mulch @5t/ha(T_1)	Farmer's Local (V_1)	Nov 30 D_2	$T_1V_1D_2$
T_3	Zero till with straw mulch @5t/ha(T_1)	WK-1204 (V_2)	Nov 15 D_1	$T_1V_2D_1$
T_4	Zero till with straw mulch @5t/ha(T_1)	WK-1204 (V_2)	Nov 30 D_2	$T_1V_2D_2$
T_5	Zero till with straw mulch@5t/ha (T_1)	Annapurna-4 (V_3)	Nov 15 D_1	$T_1V_3D_1$
T_6	Zero till with straw mulch @5t/ha(T_1)	Annapurna-4 (V_3)	Nov 30 D_2	$T_1V_3D_2$
T_7	Zero till with straw mulch @5t/ha(T_1)	Gautam (V_4)	Nov 15 D_1	$T_1V_4D_1$
T_8	Zero till with straw mulch@5t/ha (T_1)	Gautam (V_4)	Nov 30 D_2	$T_1V_4D_2$
T9	Conventional till without mulch (T_2)	Farmer's Local (V_1)	Nov 15 D_1	$T_2V_1D_1$
T10	Conventional till without mulch (T_2)	Farmer's Local (V_1)	Nov 30 D_2	$T_2V_1D_2$
T11	Conventional till without mulch (T_2)	WK-1204 (V_2)	Nov 15 D_1	$T_2V_2D_1$
T12	Conventional till without mulch (T_2)	WK-1204 (V_2)	Nov 30 D_2	$T_2V_2D_2$
T13	Conventional till without mulch (T_2)	Annapurna-4 (V_3)	Nov 15 D_1	$T_2V_3D_1$
T14	Conventional till without mulch (T_2)	Annapurna-4 (V_3)	Nov 30 D_2	$T_2V_3D_2$
T15	Conventional till without mulch (T_2)	Gautam (V_4)	Nov 15 D_1	$T_2V_4D_1$
T16	Conventional till without mulch (T_2)	Gautam (V_4)	Nov 30 D_2	$T_2V_4D_2$

3.2.4 Field layout

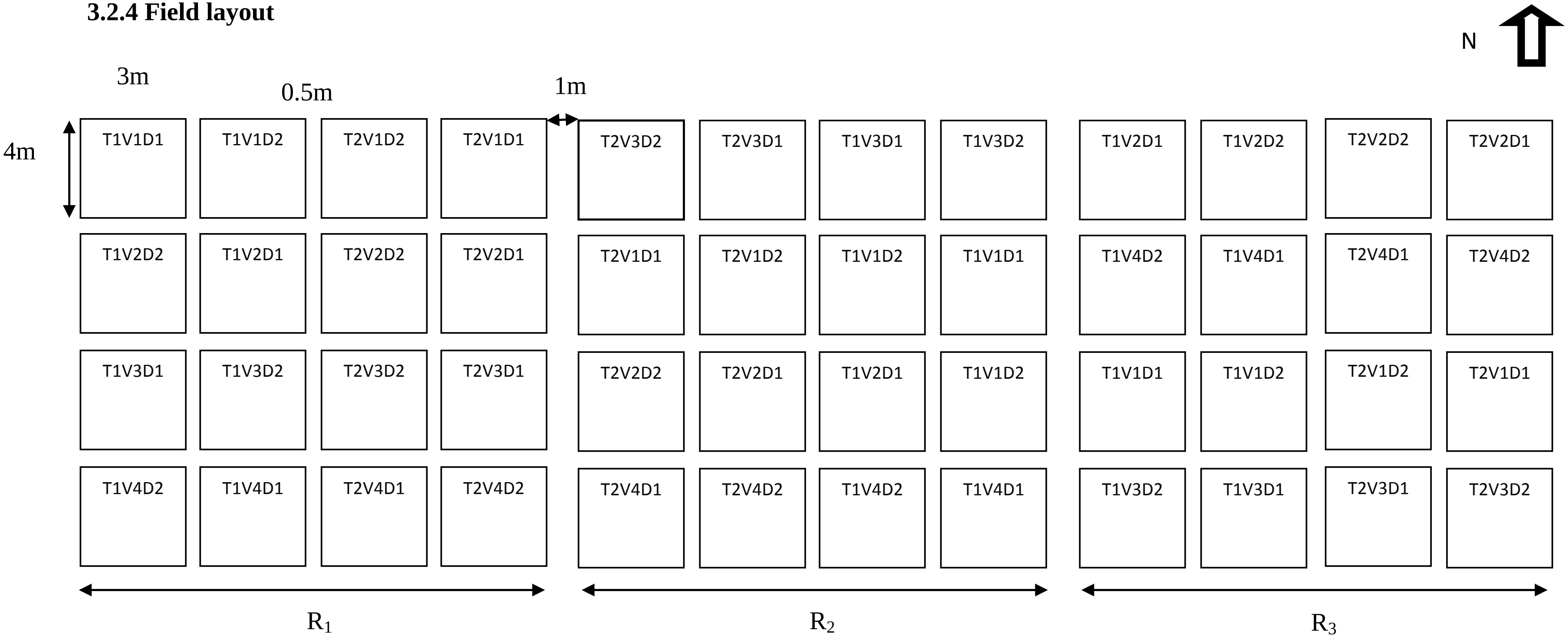

Figure 3. Lay out of the research

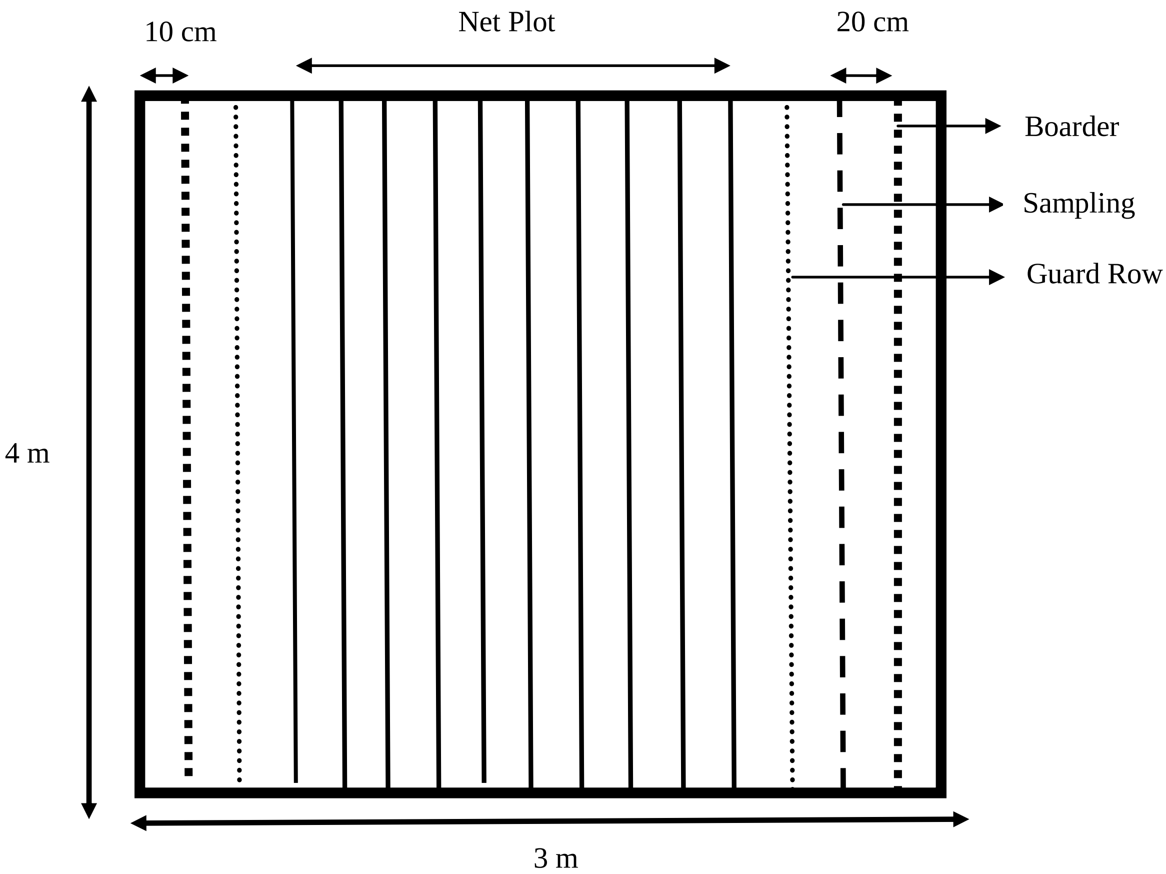

Figure 4. Individual plot layout

3.3 Varietal characteristics of wheat varieties

3.3.1WK-1204

It was developed by the combined efforts of CIMMYT Mexico and NARC through production trail, farmers trail and farmer's participatory varietal trails. It was released in 2007 for mid and high- hill region of Nepal (NARC, 2007).

It matures in about 169 days and produces an average yield of 6.9 t ha^{-1}. The variety performs better in irrigated and non irrigated high and mid-hill region of Nepal and has hard oval round white grains. Because of its better quality of non-lodging, high yield, synchronized maturity, easy threshing it is popular among farmers (NARC, 2007). Average height of this variety is 83 cm. It is resistant to yellow rust.

3.3.2 Gautam

The variety Gautam (old name BL-1887) is developed pedigree cross of Siddartha (NANGING 8319/ NL297 NC1838-4B-020B-2B-OB and was developed from the F_1

crosses and released in 2061 in Nepal (NWRP, 2011). It matures in about 105-119days and produces an average yield of 3.4 t ha^{-1}. The variety performs better in terai, *taar*, and valley below 500 masl has large, plump and elliptical shape grains with amber color. Average height of this variety is 91-95 cm. It is resistant to yellow rust. It has erect and semi- erect growth habit.

3.3.3 Farmer's Local

Farmer's Local variety is characterised by narrow leaves, tall height, and high panicle shattering and has small round shape and red color grain. It matures early than improved varieties. Average height of this variety is 100-110 cm with average yield of 3.0 t ha^{-1}.

3.3.4 Annapurna-4

This variety was released in 1994. It has broad leaves, semi-dwarf. It has large white grain having elliptical shape (SQCC, 2006). It matures in about 161 days and produces an average yield of 5 t ha^{-1}. The variety performs better in high and mid- high region of Nepal. Average height of this variety is 91-95 cm. It is resistant to yellow rust. It has erect and semi-erect growth habit.

3.4 Cultural operation

3.4.1 Land preparation

At first the layout of the field was done for the execution of treatment/experimental unit. The experimental plots were divided in to the 48 plots. For conventional tillage, plots were ploughed by animal drawn plough and then digging 2-3 times was done before 1 days of planting. For ZT, plot was prepared by furrow making spade. Well demarcated row of 1 m between each replication and 0.5 m distance between each plot was made.

3.4.2 Fertilizer application

Phosphorus and potash were applied at the rate of 60 and 40 kg ha^{-1} through the DAP and MOP. Nitrogen was applied as per the treatments 80 kg N ha^{-1} through the Urea. The half dose of nitrogen, full dose of phosphorus and potash were applied as a basal dose. The remaining half dose of nitrogen was applied 30 days after sowing.

3.4.3 Seed rate and sowing

Four wheat varieties (Farmers' Local, WK-1204, Annapurna-4 and Gautam) were seeded on two sowing dates viz: November 15 and November 30 in two establishment methods (ZT and CT) with the seed rate of 120 kg ha^{-1}. Sowing of seeds was done manually and was sown continuously maintaining 20 cm row to row spacing. Shallow furrow was made with a furrow making spade in which Urea, DAP, MOP and vermicompost was mixed and seed was continuously placed on the same day.

3.4.4 Mulching

Sown seeds were covered by soil and farm yard manure and as applied above it then straw mulch @5 t ha^{-1} were applied in zero tillage plots.

3.4.5 Irrigation

Since experiment was conducted in rainfed condition, no any irrigation was given.

3.4.6 Weeding

Two hands weeding (one at 30 DAS and second at 60 DAS) were done in the plots to reduce the competition between weeds and crop for nutrient, light, moisture and space.

3.4.7 Plant protection measures

No any insecticide and fungicide was applied as plant protection measure. For controlling grasshopper damage in the field diluted sour curd was sprayed in the field at 75 DAS.

3.4.8 Harvesting and threshing

The crop from net plot area was harvested with the help of the sickles manually. Harvested plants were left in the field for 3 days for sun drying. Threshing was done manually after sun drying of harvested crop and grains were cleaned by winnowing.

3.5 Biometrical observations

3.5.1 Leaf area index

Leaves were selected from 25 cm row of the plot except boarder from each side of net plot area. After that leaf area was measured by using scale. The leaf area so obtained was used to calculate the leaf area index.

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

3.5.2 Tillers number m^{-2}

Number of tillers m^{-2} plant was counted from 1m rows of plot. It was started to count from 15 DAS and preceded at 15 days interval till 90 DAS.

3.5.3 Dry matter accumulation

For the analysis of growth of the plant, plant samples were taken from 25 cm row of the plot except boarder from each side of the net plot area. Plant samples were taken from 30 DAS to the 120 DAS at an interval of the 15 days. Dry matter was obtained after drying above ground plant parts in an oven at a temperature of 72^{o}C for 48 hours.

3.5.4 Phenological observation

Randomly selected 10 plants of each plot were tagged from the beginning of CRI and regularly observed to notify the phenological stages (anthesis and maturity).

3.5.5 Final tillers m^{-2}

Final tillers m^{-2} were recorded from net plot area by the use of quadrate (1m×1m) before the harvesting of the crop and the values were used to obtain the tillers mortality.

3.5.6 Effective tillers m^{-2}

Observations regarding the effective tillers m^{-2} were recorded from net plot area by placing quadrate (1m×1m) before harvesting the crop and the values were used to obtain the effective tillers m^{-2}

3.5.7 Spike length

The length of the spike was taken randomly from the 10 spikes of the net plot area just before the harvesting of the crop and mean was calculated and expressed as cm.

3.5.8 Number of grains and weight $spike^{-1}$

The filled spikelets and weight of total spikelets were counted and weighted by electric balance by taking the 10 spikes from net plot a. While counting, numbers of unfilled grains and filled grains were also separated and counted to determine the sterility percentage.

3.5.9 Thousand grains weight (TGW)

Thousand grains were counted from the grain yield of net plot and weighed with the help of portable automatic electronic balance, and expressed as gram.

3.5.10 Sterility percent

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

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

3.5.11 Grain and straw yield

Six square meter of net plot area was harvested and 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 net plot area. To record the moisture percentage of the grain digital moisture meter was used. Finally grain yield was adjusted at 12% moisture using the formula as suggested by Paudel (1995).

$$\text{Grain yield (kg ha}^{-1}\text{) at 12\% moisture} = \frac{(100\text{-MC})\times\text{plot yield (kg)}\times 10000\ (\text{m}^2)}{(100\text{-}12)\times\text{net plot area (m}^2)}$$

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

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

3.5.12 Harvest index

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

HI (%) = (Grain yield×100)/ Grain yield+ Straw yield)

3.6 Statistical analysis

The data obtained from research was analyzed using MS Excel and MSTAT-C (Version 1.3, Michigan University, 1994). Analysis of variance (ANOVA) was performed to analyze differences between different experimental treatments at the 0.05 probability level and DMRT was performed for mean comparison at the 0.05 level of significance. All results presented in this study are at the $P<0.05$ levels (Gomez and Gomez, 1984).

3.7 Simulation modeling

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

3.8.1 Data requirement for model evaluation

CSM-CERES-Wheat 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. 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 A-File, T-File and X-File prepared for the wheat experiments are given in (Appendix 23) in DSSAT format.

3.8.2 Model calibration

CERES- Wheat uses eight genetic coefficients; four genetic coefficients are related to the plant development (P1V, P1D and P5). The remaining four genetic coefficients are associated with grain yield (G1, G2, G3 and PHINT) were successively estimated and found to be perfectly equal to the observed yield. Model was calibrated using following treatments

Zero tillage, Farmer's Local variety and November 15 sowing date

Zero tillage, WK-1204 variety and November 30 sowing date

Zero tillage, Annapurna-4 and November 15 sowing date

Zero tillage, Gautam and November 15 sowing date

3.8.3 Model validation

Validation of the model involves comparison of predicted and simulated data from crops that were not used for the calibration. They must be validated for the sites and regions of interests. Validation involves subjective judgment. It is a measure of accuracy or closeness of fit established for the state variable such as crop yield. The model were evaluated using the root mean sum square (RMSE) and index of agreement (d-stat) statistics (Willimott, 1985). 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). Simulation model was compared to field data not previously used in the development of calibration process. The parameters used for the validation of

CERES-Wheat were anthesis date, physiological maturity date, grain yield, and maximum leaf area index. All treatments except the treatments that used for calibration were used to validate the model.

3.8.4 Sensitivity analysis

Sensitivity analysis is a base line that enables the user to make changes to existing data sets and compare the effects of that change. *The following treatments used for the sensitivity analysis;*

Zero tillage, Farmer's Local variety and November 30 sowing date

Conventional tillage, WK-1204 variety and November 30 sowing date

Conventional tillage, Annapurna-4 and November 30 sowing date

Conventional tillage, Gautam and November 30 sowing date

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 wheat cultivar.*

4 RESULTS AND DISCUSSION

The result obtained during the experiment is presented in this chapter with the help of Tables and Figurers wherever necessary. The results obtained are discussed with possible reasons and with supporting literature.

4.1 Statistical analysis

4.1.1 Grain yield

The data on the grain yield of wheat is presented in table 6. Grain yield of wheat crop is the result of combined effect of various yield contributing components.

The grain yield of WK-1204 variety (3.11 t ha^{-1}) was significantly higher than other varieties Annapurna-4 (2.88 t ha^{-1}), Farmer's Local (2.61 t ha^{-1}) and Gautam (2.44 t ha^{-1}). The higher grain yield of WK-1204 variety was attained due to higher number of total tillers and fertile tillers, more number of grains $spike^{-1}$ and 1000-grain weight as compared to other varieties (Table 8). Filled grains/ spike of the WK-1204 were also higher than the other varieties. This may be due to inherent differences between the cultivars in the yield components like the number of tillers per plant, number of grains per spike and 1000 grain weight (Suleiman *et. al*., 2014).

It was revealed that WK-1204 produced 14% more yield than the average of other varieties. The mean grain yield of wheat was the highest (3.58 t ha^{-1}) in ZT as compare to CT plot. These results were approved with the results found by Juan *et al* (2008) who reported that wheat crop had given a higher grain yield under zero tillage compared with conventional tillage. Result was also supported Jat *et al* (2009), that zero tillage was equal or better than conventional tillage in many crops and economic traits, in addition to a clear improvement in soil properties, water conservation and erosion resistance. It is so because more water is accumulated in soil tilled according to zero tillage method, which is a consequence of lower evaporation and changes in the soil's water permeability when no mechanical soil tillage is involved (Rasmussen, 1999; Martinez *et al*., 2008).

Interaction effect was found significant between Tillage, Varieties and sowing dates on grain yield of Wheat. Grain yield of WK-1204 variety at both sowing dates (3.39 t ha^{-1} in November 15 and 3.56 t ha^{-1}in November 30) under ZT was found significantly higher but it was statistically at par with Annapurna-4 (3.31 t ha^{-1}). There was statistically similar yield of Gautam (2.78 t ha^{-1}) and farmer's local (2.83 t ha^{-1}) under ZT. In general WK-1204 variety, performed better than other three varieties in both tillage practices. Higher grain yield from zero tillage might be due to better utilization of soil moisture, improved infiltration, lower fluctuation in soil temperature and better root growth (Bauer *et al.,* 2002). Halvorson *et al.* (2000) reported greater grain yield of wheat from zero tillage than minimum tillage and conventional tillage. Similar grain yields from zero, reduced and conventional tillage was also reported by several researchers (Iqbal *et al.,* 2002).

The greater reduction in yield of late matured wheat varieties under delayed sowing situations was attributed to decrease in growing season resulting reduction in their potential yield. Delayed sowing hastened the crop phenological development, thereby causing significant reduction in wheat yields (Singh and Pal, 2003). Kaur *et al*. (2010) and Pandey *et al*. (2010) also reported the similar observation under delayed sowing (Ram *et al*., 2012). Interaction effect of tillage and sowing date on grain yield was also found significant (Figure 5).

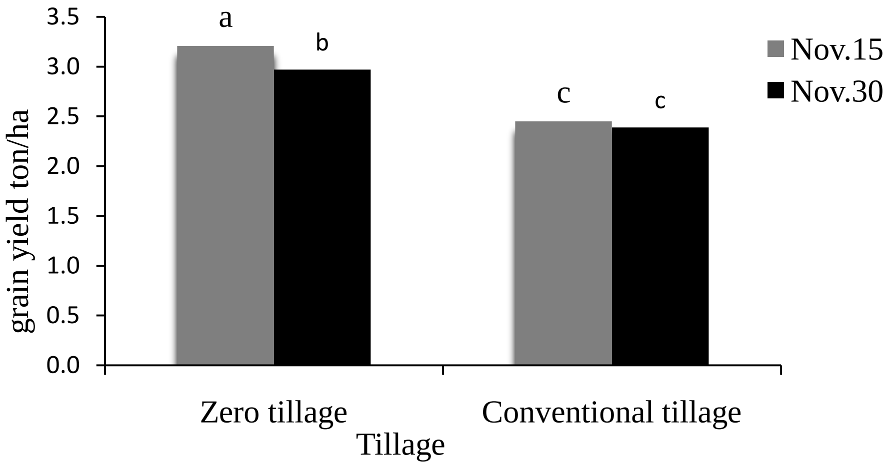

Figure: 5. Interaction effect of tillage and sowing date on grain yield

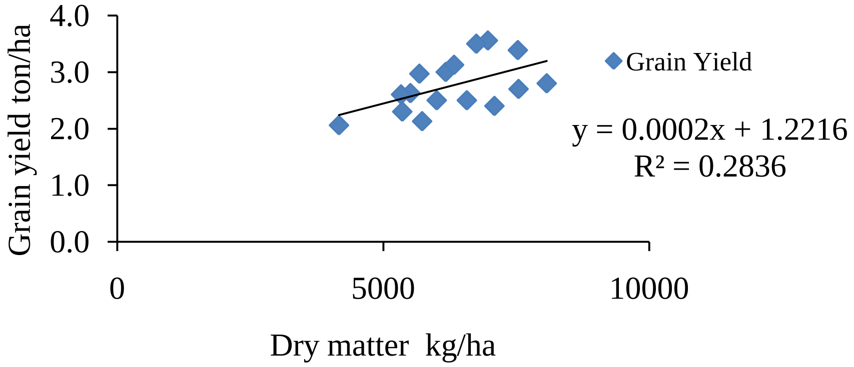

Figure 6. Linear regression between grain yield and dry matter

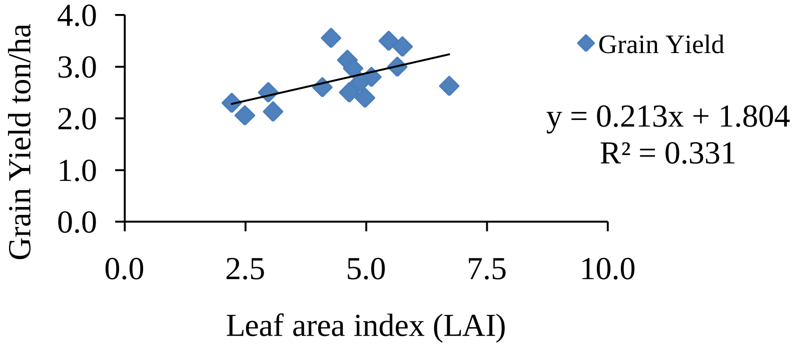

Figure 7. Linear regression between grain yield and leaf area index

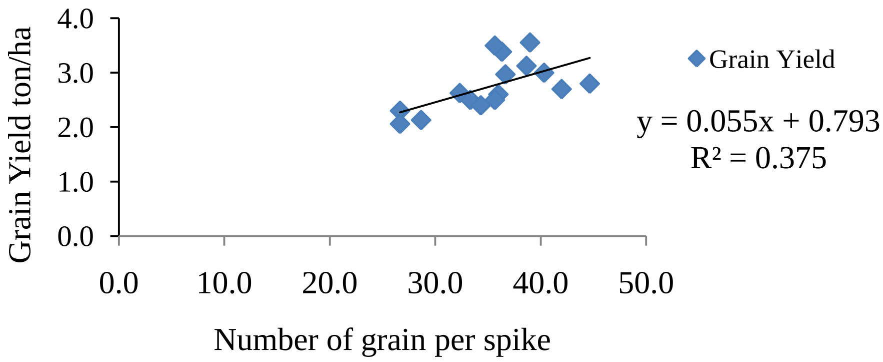

Figure 8. Linear regression between grain yield and number of filled grain per spike

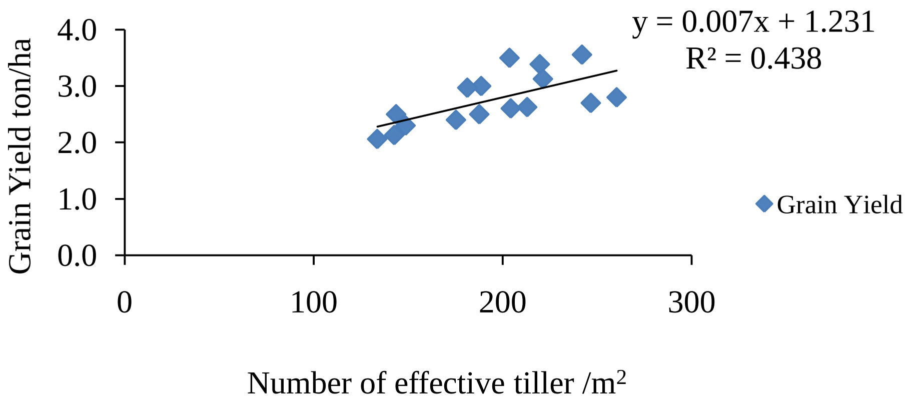

Figure 9. Linear regression between grain yield and Number of effective tiller /m^2

Table 6. Interaction effect of tillage, varieties and sowing date on grain yield of wheat at Dhikurpokhari, Kaski 2014/15

Varieties	ZT		CT	
	15-Nov	30-Nov	15-Nov	30-Nov
Farmers' local	3.00b[c]	2.63[def]	2.50[efg]	2.30[gh]
WK 1204	3.39[a]	3.56[a]	2.80[cd]	2.70[de]
Annapurna 4	3.50[a]	3.13[b]	2.40[fg]	2.50[efg]
Gautam	2.97[bc]	2.60[def]	2.13[h]	2.06[h]
SEm	0.08			
LSD	0.23			

4.1.2 Straw yield

Straw yield was significantly higher (3.77 ton ha^{-1}) in ZT than CT (3.44 ton ha^{-1}) (Table 6). Higher straw yield from zero tillage might be due to conservation of soil moisture and better nutrient uptake from zero tilled plots. Result was in line with Singh *et al.* (2006) who reported the highest mean straw yield of wheat in zero tillage.

Straw yield was significantly affected by varieties. Significantly higher straw yield was obtained from WK-1204 variety (3.84 ton ha^{-1}) followed by Annapurna-4 (3.67 ton ha^{-1}) ,Gautam (3.55ton ha^{-1}) and Farmers Local (3.38ton ha^{-1}). But straw yield of Annapurna-4 was statistically at par with straw yield of Gautam. The result was in conformity with Poudel *et al* (2013) who obtained maximum straw yield from WK-1204 (4.5 ton ha^{-1}) than other improved varieties and Farmers Local. Straw yield was also significantly influenced by sowing date. Significantly higher straw yield was obtained from November 15 sowing (3.65 ton ha^{-1}) as compared to November 30 sowing (3.57 ton ha^{-1}). A similar result was found by Anwar *et al*. (2015). This might be due to more suitable climatic conditions for maximum vegetative and reproductive growth of wheat. Interaction between tillage and sowing dates, tillage and varieties and varieties and sowing dates were also found significant (Appendices 8, 9, 10)

4.1.3 Harvest index

There was significant influence of tillage and varieties on harvest index (HI). Significantly higher HI was obtained from ZT (50.60) compared to CT (41.34). Higher HI was obtained from WK-1204 (47.53). HI of WK-1204 was statistically at par with Annapurna-4 (46.66) and Farmer's Local (46.39). The lowest HI was obtained from Gautam (43.35). Effect of tillage was not significant on HI.

Interaction between tillage and variety was found significant (Appendix 8). Higher HI was obtained from WK-1204 (51.17) under ZT which was statistically at par with HI of other three varieties Annapurna-4 (51.01), Gautam (50.27) and Farmer's Local (50.04). Interaction effect of tillage and varieties on HI were found significant (Appendix 8).

Table 7. Effects of sowing dates, tillage and varieties on grain yield, straw yield and harvest index of wheat at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})	Harvest Index (%)
Tillage			
ZT	3.10[a]	3.77[a]	50.62[a]
CT	2.42[b]	3.44[b]	41.34[b]
SEm(±)	0.02	0.02	0.28
$LSD_{(0.05)}$	0.18	0.18	2.13
Varieties			
Farmers Local	2.61[c]	3.38[b]	46.39[a]
WK-1204	3.11[a]	3.84[a]	47.53[a]
Annapurna-4	2.88[b]	3.67[b]	46.66[a]
Gautam	2.44[c]	3.55[c]	43.35[b]
SEm(±)	0.05	0.03	0.33
$LSD_{(0.05)}$	0.17	0.13	1.74
Sowing Date			
Nov. 15	2.84[a]	3.65[a]	46.41[a]
Nov. 30	2.68[b]	3.57[b]	45.55[a]
SEm (±)	0.02	0.02	0.45
$LSD_{(0.05)}$	0.10	0.09	1.16
CV %	4.98	3.46	3.39
GM	2.76	3.60	45.98

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level. CT=conventional tillage; ZT-zero tillage.

4.2 Yield attributes

Various yield attributing characters of wheat viz. effective tillers number per meter square, spike weight, spike length, filled grains number, sterility percentage, and thousand grains weight taken at harvest varied significantly due to the tillage practices, varieties and sowing dates.

The higher value of yield attributing parameters and yield in case of early sowing over delayed ones could be attributed to availability of optimum environmental conditions for growth and development of crop which might enhance accumulation of photosynthates from source to sink (Ram *et al*, 2012).

4.2.1 Effective tillers

Tillage and varieties had significant effect on effective tillers of wheat varieties. ZT produced significantly higher number of effective tillers (209.25) compared to CT (197.83). The effective tillers were significantly higher on WK-1204 as compared to other wheat varieties (Table 8). The highest effective tillers were recorded on WK-1204 (242.17) which was significantly higher than Annapurna-4 (186), Farmer's Local (184.50) and Gautam (165). Higher effective tillers in WK-1204 might be due to more germination count and total number of tillers as compared to the other three varieties. Hussain *et al.* (2001) also found the highest number of effective tillers in heat stress tolerant variety of wheat. There was positive correlation between effective tillers and grain yield (R^2=0.438) (Figure 8).

There was significant interaction among tillage and varieties on effective tillers of wheat (Figure 10). Significantly higher number of effective tillers was produced by WK-1204 under ZT (253.50). Tillage and sowing date also had significant interaction effect on effective tillers (Figure 11). Significantly higher numbers of effective tillers were produced in ZT plot sown on November 15 (220.2).

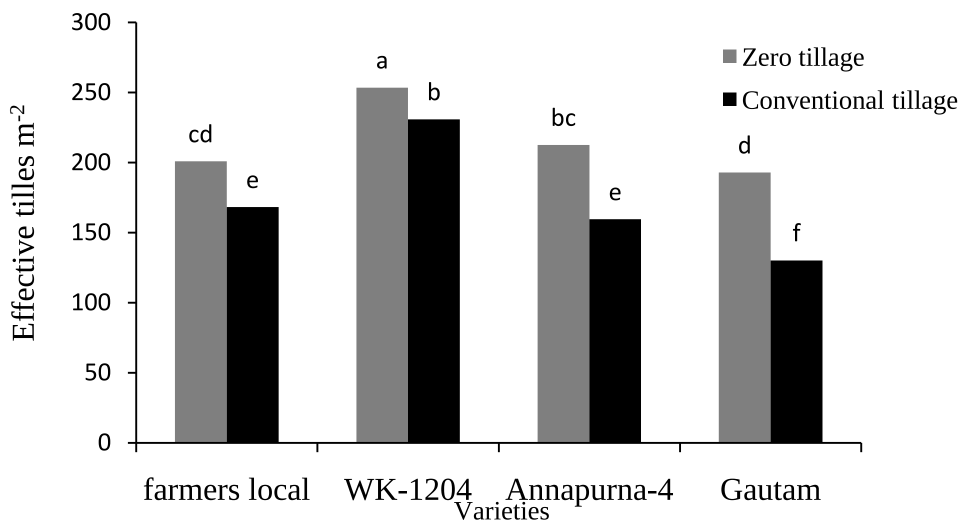

Figure 10. Interaction effect of tillage and varieties on effective tillers m^{-2}

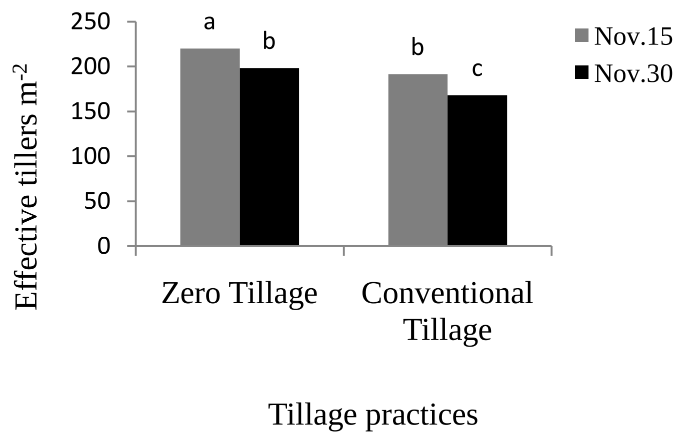

Figure 11. Interaction effect of tillage and sowing date on effective tillers m^{-2}

4.2.2 Spike weight

Significantly heavier spike (2.08g $spike^{-1}$) was obtained in ZT as compared to CT (1.93g $spike^{-1}$). It was revealed that Annapurna-4 (2.42g $spike^{-1}$) had heavier spike followed by Gautam (2.06g $spike^{-1}$) and WK-1204 (2.05g $spike^{-1}$). The lowest spike weight was obtained in Farmers Local variety (1.49 g $spike^{-1}$) and that might be due to higher number of filled grains as compared to local variety (Table 8). Significantly higher spike weight was obtained from November 15th sowing (2.15 g $spike^{-1}$) as compared to sowing on November 30th (1.86 g $spike^{-1}$).

Interaction effect of tillage and varieties was also found significant on pike weight (Appendix 17). Interaction effect of tillage and sowing date had significant influence on spike weight. Higher spike weight was observed on ZT sown in November 30th (Appendix 16). Interaction effects of variety and sowing date were also found significant. Annapurna-4 variety produced heavier spike on November 15 sowing (Appendix 18).

4.2.3 Spike length

Effect of tillage on spike length was not significant; however variety exhibited significant effect on spike. Spike length was longer in WK-1204 (9.18 cm) as compared to other varieties of wheat (Table 8). But spike length of WK-1204 was statistically at par with Annapurna-4 (9.14 cm) and Gautam (9.06 cm). Spike length was obtained significantly longer on November 15th sowing (8.79 cm) compared to November 30th sowing (8.49 cm). Similar results were obtained by Gizaway (2009). The spike length probably decreased due to delay in sowing because of the sensitivity of the wheat plants to photoperiod and temperature (Slafer and Whitechurch, 2001).Interaction effect of tillage and varieties on spike length was found significant (Appendix 14).

4.2.4 Thousand grain weight (TGW)

It was observed that1000-grain weight was not influenced by tillage practice. The 1000-grain weight was significantly influenced by varieties (Table 8). The highest 1000-grain weight was recorded on Annapurna-4 (42.85 g) and was significantly higher than the 1000-grain weight of WK-1204 (40.98 g) and Gautam (40.70 g). The lowest 1000-grain weight of Farmers Local might be due to its smaller grain. Higher 1000-grain weight of Annapurna-4 might be due to the bold grain size as compared to other wheat varieties. Sowing date had significant influenced on 1000-grain weight. It was significantly higher on November 15th sowing (38.18 g) compared to November 30th sowing (37.17 g). Similar result was obtained by Said *et al*., (2012). The 1000-grains weight probably decreased due to delay in sowing because the wheat plants may not have got sufficient time to increase the grain size sufficiently because of longer photoperiod and higher temperature under late planting (Slafer and Whitechurch, 2001: Tahir *et al*., 2008). .

4.2.5 Filled grains per spike

It was observed that filled grains per spike was not influenced by tillage practice, however variety and sowing date exerted significant result. Significantly higher filled grains /spike were obtained from WK-1204 (40.50) than other three varieties. The highest filled grain per spike recorded from WK-1204 (40.50) was significantly higher than Annapurna-4 (36.08) and Farmers Local (33.17) and Gautam (32). Higher filled grains per spike of WK-1204 were due to its genetic behavior. Padmajarao (1995) reported that the yield component such as grain number was influenced by dry matter production reflecting in higher photosynthetic efficiency. There was also record of significant positive correlation between the filled grains/spike and grain yield (R^2=0.375) (Figure 8). There was insignificant effect of sowing date on filled grains/ spike. But higher number of filled grain/spike was obtained from Nov 30 sowing (36.35) compared to Nov 30 sowing (34.03).

There was significant interaction between tillage and varieties on filled grains per spike (Appendix 14). Significantly higher filled grain per spike was recorded on WK-1204 under ZT (43.33). The grains per spike seemed to have decreased due to delay in sowing because of the sensitivity of the wheat plants to photoperiod and temperature (Slafer and Whitechurch, 2001). As the photoperiod and temperature increased, proper fertilization of the ovule may not have occurred to produce grains.

The number of grains per spike showed a descending order with the order of planting dates from November 15th to November 30th planting and this may be due to high temperature at grain filling. Similar results were reported by Ishaq *et al*. (1993) and proved that high temperatures decreased the number of grains per spike due to fewer grains per spikelet.

4.2.6 Sterility percentage

Different tillage practices did not differ significantly by sterility percentage (Table 8). There was significant influence of varieties on sterility %. It was significantly higher on Farmer's Local (15.9%) as compared to the other improved varieties (Table 8). Significantly lower sterility% was obtained on WK-1204 (7.06%). Sowing date had significant influence on sterility% of wheat. Sterility% of wheat sown on November 15th was significantly lower (9.11%) than November 30th (10.84%) sowing. It might be due to higher number of filled grain in early sowing. Varietal differences in terms of spikelet sterility observed in the present investigation were agreed well with the findings of Subedi *et al*. (1993). Spikelet sterility in different wheat varieties differed probably due to difference in genetic characters Joshi and Sthapit (1996). Spikelet sterility occurs due to the differences of plant developmental stages among the varieties and also environmental conditions which prevailed during the reproductive developmental stages (Saifuzzaman *et al*., 2008). There was significant interaction between tillage and date of sowing on sterility % (Appendix15). Higher sterility % was reported in wheat under CT sown in Nov 30 (11.66) and lowest was recorded from ZT sown on Nov 15 (8.95).

Table 8. Yield attributes of wheat as influenced by tillage, varieties and sowing dates at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Effective tillers (No m^{-2})	Spike weight (g)	Spike length (cm)	Filled grain (No $panicle^{-1}$)	Sterility (%)	Test weight (g)
Tillage						
ZT	209.25^a	2.08^a	8.69	36.88	9.49	38.49
CT	179.83^b	1.93^b	8.59	34.00	10.47	37.48
SEm (±)	3.27	0.01	0.12	067	0.10	0.24
LSD $_{(0.05)}$	24.44	0.12	ns	ns	ns	ns
Varieties						
Farmer's Local	184.50^b	1.49^c	7.17^b	33.17^b	15.94^a	27.42^c
WK-1204	242.17^a	2.05^b	9.18^a	40.50^a	7.06^c	40.98^b
Annapurna-4	186.00^b	2.42^a	9.14^a	36.08^b	8.83^b	42.85^a
Gautam	165.50^b	2.06^b	9.06^a	32.00^b	8.08^b	40.70^b
SEm (±)	6.71	0.05	0.24	1.20	0.22	0.52
LSD$_{(0.05)}$	23.24	0.20	0.83	4.16	0.78	1.8
Sowing Date						
Nov. 15	194.92	2.15^a	8.79^a	36.25	9.11^b	38.81^a
Nov. 30	194.17	1.86^b	8.49^a	34.63	10.84^a	37.17^b
SEm (±)	3.15	0.04	0.12	0.87	0.22	0.31
LSD$_{(0.05)}$	ns	0.14	0.31	ns	0.82	1.14
GM	194.54	2	8.64	35.43	9.97	37.98
CV %	7.95	9.76	4.89	12.11	10.98	4.01

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, ns: not significant. CT=conventional tillage; ZT-zero tillage.

4.3 Biometric observation

4.3.1 Number of tillers m^{-2}

There was no significant influence of tillage on numbers of tillers m^{-2}. Number of tillers m^{-2} was significantly affected by different wheat varieties (Table 9). Significantly higher number of tillers m^{-1} was recorded in WK-1204 variety (334.75) at 15 DAS, (353.75) at 30 DAS, (356.58) at 45 DAS, (361.67) at 60 DAS, (356.83) at 75 DAS, (350.42) at 90 DAS and (315) at harvest as compared to other three wheat varieties. Among other three wheat varieties higher number of tillers $m^{-1}$was recorded in Annapurna-4 followed by Farmers Local and Gautam. This may be attributed to different capacity of cultivars in tillering, These findings in agreement with Ishq (1996) who reported that tillers were initiated at leaf stages and cultivars differed in their tillering capacity. The process of tillering is mainly controlled by genetic and environmental factors (Longnecker *et al*., 1993). Tiller number was decreased after 60 DAS in all wheat varieties which was due to tiller mortality.

Sowing date also had significant influence in tiller number per meter square. Significantly higher number of tillers m^{-1} was recorded on November 30^{th} sowing as compared to November 15^{th} sowing in all observations.

Table 9. Effect of tillage, variety and date of sowing on tiller number per meter square of wheat at different sowing date at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Tiller number per meter square						
	Days after sowing						
	15	30	45	60	75	90	At Harvest
Tillage							
ZT	304.54	316.54	332.54	339.58	330.04	328.29	299.21
CT	279.96	294.92	301.46	296.25	266.67	268.33	254.67
SEm(±)	9.80	8.58	8.16	4.65	7.23	6.51	6.24
$LSD_{(0.05)}$	ns	ns	ns	ns	ns	Ns	ns
Varieties							
Farmer's Local	289.42^{ab}	299.83^{b}	317.92^{ab}	314.17^{ab}	282.92^{bc}	290.42^{b}	279.67^{a}
WK-1204	334.75^{a}	353.75^{a}	356.58^{a}	361.67^{a}	356.83^{a}	350.42^{a}	315.00^{a}
Annapurna-4	276.00^{b}	289.50^{b}	300.58^{b}	313.33^{ab}	304.83^{ab}	302.00^{ab}	299.58^{a}
Gautam	268.83^{b}	279.83^{b}	292.92^{b}	282.50^{b}	248.83^{c}	250.42^{b}	213.50^{b}
SEm(±)	10.03	13.38	14.58	14.04	15.27	16.30	10.84
$LSD_{(0.05)}$	10.04	46.31	50.48	48.62	52.48	56.43	37.51
Sowing Date							
Nov. 15	313.96^{a}	326.00^{a}	336.71^{a}	335.21^{a}	318.38^{a}	316.42^{a}	295.67^{a}
Nov. 30	270.54^{b}	285.46^{b}	297.29^{b}	300.63^{b}	278.33^{b}	280.21^{b}	258.21^{b}
SEm(±)	6.42	6.80	7.29	6.23	4.74	5.88	3.76
$LSD_{(0.05)}$	23.69	24.97	26.29	22.88	17.42	21.60	13.83
GM	292	305.72	317	318.91	298.35	298.31	276.98
CV,%	10.78	10.90	11.28	9.60	7.79	9.66	6.66

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, ns: not significant. CT=conventional tillage; ZT-zero tillage.

4.3.2 Leaf area index

The data on the leaf area index (LAI) of wheat is presented in Table 9. Leaf area index differed significantly due to the tillage practices, varieties and sowing dates. Significantly higher LAI was observed in ZT plot (0.42, 0.98, 2.99, 5.01, and 5.16) at 30, 45, 60, 75 and 90 DAS; respectively as compared to CT plot (0.29, 0.63, 2.10, 3.75, and 3.79).

Variety WK-1204 had higher LAI as compared to other three varieties. It was found that leaf area index of all varieties goes increasing up to 90 DAS then started declining. The senescence of lower leaves and withering decreases LAI in later developmental stage. It was raveled that leaf area index of WK-1204 ranged from 0.46 at 30 DAS to 5.16 at 90 DAS whereas in Annapurna-4 it ranged from 0.37 at 30 DAS to 4.55 at 90 DAS. The LAI in Gautam ranged from 0.31 at 30 DAS to 4.39 at 90 DAS and in Farmers Local it ranged from 0.29 at 4.81 DAS to 3.284 at 90 DAS. This may be referred to inherent difference between cultivars for leaf area index, number of leaves per plant and their tillering capacity during growing seasons (Suleiman *et al*, 2014).

November 15 Sowing produced significantly higher leaf area index than November 30 sowing for all growth stages. It was found that leaf area index of November 15 sowing ranged from 0.38 at 30 DAS to 4.91 at 90 DAS whereas it was ranged from 0.33 at 30 DAS to 4.33 at 90 DAS for November 30 sowing. Interaction effect of tillage and sowing date on LAI at 90 DAS is in figure 12.

Table 10. Effect of tillage, variety and date of sowing on leaf area index of wheat at growth stages at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Leaf area index (LAI)				
	Days after sowing (DAS)				
	30	45	60	75	90
Tillage					
ZT	0.42[a]	0.98[a]	2.99[a]	5.01[a]	5.16a
CT	0.29[b]	0.63[b]	2.10[b]	3.75[b]	3.79
SEm(±)	0.08	0.03	0.07	0.08	0.03
$LSD_{(0.05)}$	0.06	0.04	0.58	0.59	0.27
Varieties					
Farmers					
Local	0.29[c]	0.60[c]	2.45[b]	4.06[c]	4.81[ab]
WK-1204	0.46[a]	1.42[a]	3.57[a]	4.78[a]	5.00[a]
Annapurna-4	0.37[b]	0.72[b]	2.52[b]	4.50[b]	4.55[b]
Gautam	0.31[c]	0.48[d]	2.63[c]	4.16[c]	4.39[c]
SEm(±)	0.09	0.05	0.10	0.05	0.10
$LSD_{(0.05)}$	0.03	0.03	0.35	0.17	0.35
Sowing Date					
Nov. 15	0.38[a]	0.97[a]	2.76[a]	4.87[a]	4.92[a]
Nov. 30	0.33[b]	0.64[b]	2.33[b]	3.89[b]	4.03[b]
SEm (±)	0.08	0.05	0.07	0.07	0.06
$LSD_{(0.05)}$	0.03	0.02	0.26	0.26	0.24
GM	0.35	0.80	2.54	4.38	4.47
CV %	11.04	3.59	13.83	8.13	7.22

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level. CT=conventional tillage; ZT-zero tillage.

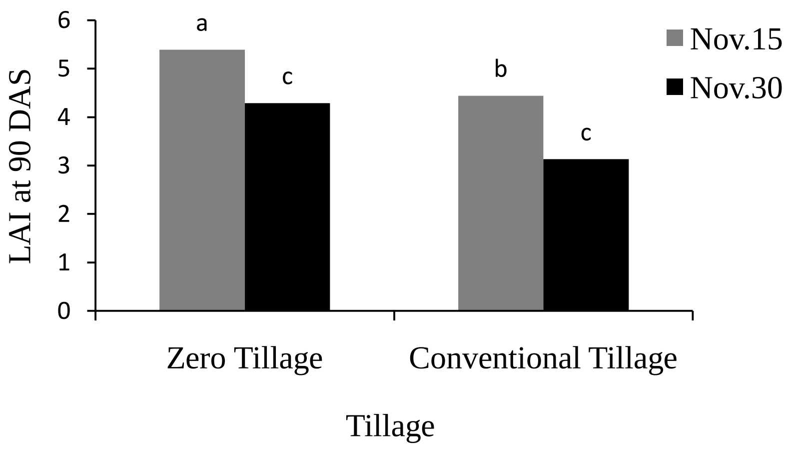

Figure 12. Interaction effects of tillage and sowing dates on LAI at 90 DAS

4.3.3 Above ground dry matter production (AGDM)

Dry matter production was varied due to different tillage practices, wheat varieties and sowing date. Dry matter accumulation due to tillage was not significant at 30 DAS there after dry matter accumulation was significant up to 90 DAS. Thereafter, there was no significant effect of tillage on dry matter accumulation. Singh *et al.* (2006) also obtained higher dry matter from ZT as compared to CT.

WK-1204 wheat variety had significantly higher dry matter production as compared to other wheat varieties. The higher dry matter production on WK-1204 was due to an increased growth rate during early vegetative stages as a result of rapid expansion of leaf area and greater tillers number (Table 9). Significantly higher DM accumulation was found in November 15 sowing date as compare to November 30 for all growth stages of wheat except for 45 DAS in which it was higher in November 30 sowing date. There was significant positive correlation between total dry matter with grain yield as 120 DAS (R^2=0.28).

Table 11. Effect of tillage, variety and date of sowing on above ground dry matter accumulation of wheat at different sowing date at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Above ground dry matter (kg ha^{-1})						
	Days after sowing (DAS)						
	30	45	60	75	90	105	120
Tillage							
ZT	167.83	361.13[a]	936.29[a]	2508.67[a]	4328.00[a]	5816.04	6286.42
CT	144.58	298.79[b]	760.92[b]	1615.58[b]	3601.88[b]	5623.75	6319.13
SEm (±)	0.29	0.46	3.31	4.59	6.45	43.83	139.46
LSD $_{(0.05)}$	ns	3.45	24.71	34.21	40.09	Ns	ns
Varieties							
Farmers Local	135.17[b]	268.75[d]	961.17[b]	1780.42[d]	3469.08[d]	5145.67[c]	5905.42[bc]
WK-1204	184.67[a]	396.00[a]	1030.58[a]	2580.75[a]	4377.50[a]	6677.25[a]	7529.58[a]
Annapurna -4	171.33[a]	358.92[b]	769.33[c]	1921.67[c]	4270.00[b]	6107.50[b]	6545.83[b]
Gautam	133.67[b]	296.17[c]	633.33[d]	1965.67[b]	3743.17[c]	4949.17[c]	5230.25[c]
SEm(±)	7.45	2.22	7.70	5.86	10.00	91.03	215.26
LSD$_{(0.05)}$	25.79	7.69	26.66	20.28	14.16	315.5	744.9
Sowing Date							
Nov. 15	194.50[a]	346.54[a]	886.21[a]	2271.79[a]	4260.79[a]	5962.17[a]	6701.42[a]
Nov. 30	117.92[b]	313.38[b]	811.00[b]	1852.46[b]	3669.08[b]	5477.63[b]	5904.13[b]
SEm (±)	4.75	1.31	3..76	7.88	46.17	49.42	77.78
LSD$_{(0.05)}$	17.44	4.84	13.84	28.96	169.6	181.5	285.6
GM	156.21	329.95	884.60	2062	3964	5719	6302
CV %	14.90	1.96	2.18	1.87	5.71	4.23	6.05

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, ns: not significant. CT=conventional tillage; ZT-zero tillage.

4.3.4 Plant height

There was non significant effect of tillage on plant height up to 45 DAS. Only after 60 DAS, plant height was significantly affected by tillage practices. Plant height was ranged from 39.39 cm to 97.28 cm from 60 to 120 DAS in zero tillage, which was significantly higher as compared to conventional tillage (33.48 cm at 30 DAS to 91.27 cm at 120 DAS). This may be due to higher organic matter contents in Zero tillage which has directly affected the vegetative growth of wheat. (Ali *et al* 2013)

Plant height of wheat varieties was significantly different at various growth stages (Table 9). From the initial to later growth stages (30 to 120 DAS) Farmer's Local was recorded significantly taller (21.25 cm) and 113.57 cm plant height at 30 DAS and 120 DAS) than other three varieties. The plant height was also significantly affected by sowing dates. Wheat sown in November 15 had significantly higher (18.90 cm) plant height at 30 DAS to 97.08 at 120 DAS than sown in November 30 (16.73 cm at 30 DAS and 91.47 at 120 DAS) throughout the different growth stage of wheat. The result was agreed with the statement of Pandey *et al.* (2013). Early sown crop had longer vegetative growth period than late sown crop which resulted in more plant height (Quasim *et al*., 2008). Wheat stops vegetative growth in terms of plant height and produces spikes after meeting the photoperiodic requirements, which results in shorter height in late sowing (Innamullha *et al*., 2007).

Table 12. Effect of tillage, variety and date of sowing on plant height of wheat at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatments	Plant height (cm)					
	Days after sowing (DAS)					
	30	45	60	75	90	120
Tillage						
ZT	17.92	24.89	39.39[a]	57.25[a]	70.29[a]	97.28[a]
CT	17.71	22.78	33.48[b]	48.36[b]	61.09[b]	91.27[b]
SEm (±)	0.29	0.59	0.83	1.07	1.06	0.63
LSD $_{(0.05)}$	ns	ns	6.25	7.98	7.95	4.69
Varieties						
Farmers						
Local	21.25[a]	28.78[a]	49.59[a]	72.95[a]	89.13[a]	113.57[a]
WK-1204	18.25[b]	23.70[b]	35.13[b]	52.96[b]	65.86[b]	91.54[b]
Annapurna-4	15.33[bc]	19.95[c]	28.90[d]	41.88[c]	51.73[d]	83.39[c]
Gautam	16.43[c]	22.91[b]	32.11[c]	43.43[c]	56.05[c]	88.60[b]
SEm (±)	0.57	0.71	0.86	0.88	1.00	0.87
LSD $_{(0.05)}$	1.97	2.48	2.97	3.06	3.46	3.08
Sowing Date						
Nov. 15	18.90[a]	25.11[a]	37.32[a]	56.72[a]	66.88[a]	97.08[a]
Nov. 30	16.73[b]	22.56[b]	35.55[b]	48.88[b]	64.50[b]	91.47[b]
SEm (±)	0.32	0.41	0.44	0.54	0.47	0.85
LSD $_{(0.05)}$	1.20	1.51	1.63	2.00	1.74	2.28
GM	17.81	23.83	36.43	52.80	65.69	94.27
CV %	9.02	8.50	5.98	5.05	3.55	4.42

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, ns: not significant. CT=conventional tillage; ZT-zero tillage.

4.4 Phenological observation

Most of the phonological stages of wheat were significantly influenced by varieties and sowing dates but the effects of tillage was non significant.

4.4.1 Heading stage

Data showed that the average days to heading was recorded as 101.93 days. There was significant difference on heading days among different wheat varieties and date of sowing. Heading was delayed in WK-1204 (107.42 days) followed by Gautam (102.42 days) and Annapurna-4 (100.98 days) but early heading was found in Farmer's Local

(97.00 days). Similarly, there was significant effect of sowing dates on heading stage initiation of wheat. Early sowing (Nov. 15) showed delayed heading (103.57 days) as compared to delayed sowing i.e. November 30 sowing (100.17 days). Delayed heading in November 15th sown wheat may be due to requirement of higher number of days for attaining heading stage (Sikder, 2009).

4.4.2 Anthesis days

The average days to anthesis was recorded as 113.93 days. There was significant variation among different wheat varieties on anthesis days (109-114 days) was noted. Early anthesis was attained in Farmer's Local (109 days) followed by Annapurna-4 (112.58 days), Gautam (114.42 days) and WK-1204 (119.75 days). Anthesis days were also affected by sowing dates. Early anthesis (112.33 days) was observed on November 30th sown wheat and it was delayed (115.54 days) on November 30th sown wheat. Early anthesis in November 30th sown wheat might be due to reduction in grain filling period.

4.4.3 Physiological maturity

The average days to physiological maturity was recorded as 149.36 days. There was significant variation among different wheat varieties on physiological maturity days (141-150 days) was occurred. Earliness on physiological maturity was attained in Farmer's Local (141.58 days) followed by Annapurna-4 (148.67 days), Gautam (150.83 days) and delayed on WK-1204 (153.91 days). Physiological maturity days were affected by sowing dates too. Early physiological maturity (145.46) was observed in November 30 sown wheat and it was delayed (152.33 days) in November 15th sown wheat. Early physiological maturity in November 30th sown wheat might be due to reduction in grain filling period. Similar results were recorded by Sikder (2009) who observed 118 days for November 30 sowing and 107 days in December 30 sowing.

Table 13. Effect of tillage, variety and date of sowing on phenology of wheat at Dhikurpokhari, Kaski, Nepal, 2014/15

Treatment	Heading days	Anthesis days	Physiological maturity days
Tillage			
ZT	102.92	114.92	148.29
CT	100.79	112.96	149.50
SEm(±)	0.38	0.71	0.60
$LSD_{(0.05)}$	ns	ns	Ns
Varieties			
Farmer's local	97.00[c]	109.00[c]	141.58[c]
Wk-1204	107.42[a]	119.75[a]	153.91[a]
Annapurna-4	100.58[b]	112.58[b]	148.67[b]
Gautam	102.42[b]	114.42[b]	150.83[b]
SEm(±)	0.71	0.73	0.70
$LSD_{(0.05)}$	2.48	2.53	2.43
Sowing Date			
Nov. 15	103.54[a]	115.54[a]	152.33[a]
Nov. 30	100.17[b]	112.33[b]	145.46[b]
SEm (±)	0.47	0.44	0.34
$LSD_{(0.05)}$	1.76	1.63	1.28
GM	101.85	113.93	149.36
CV %	2.31	1.92	1.15

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, ns: not significant. CT=conventional tillage; ZT-zero tillage.

4.5 Agro climatic indices

4.5.1 Growing degree day (GDD)

It was observed that the combined effect of growing conditions and cultivars on heat unit (GDD) was significant at Physiological maturity stages (Table 14). Under normal growing condition WK-1204 needed the highest heat unit (1735.90) which was followed by Gautam (1719.83), Annapurna-4 (1711.52), whereas Farmers Local required the lowest heat unit (GDD) for attaining physiological maturity. At late planting condition all the cultivars showed reduced heat unit (GDD) requirement for attaining different phonological stages of growth. In late sowing condition again cultivar WK-1204 showed the highest GDD (1705.96) for attaining PM followed by Gautam (1651.26), Annapurna-4 (1637.57) whereas Farmers Local had the lowest heat unit requirements (1556.40) for attaining PM (Table 14). The requirement of heat unit (GDD) was higher for normal growing condition than the late growing condition. This was due to longer period for PM in the normal growing condition because crop passes through longer cold temperature late planting. Comparative heat tolerant cultivars obtained higher GDD than those of heat sensitive ones for their longer phenological stages. Paul and Sarker (2000) and Bishnoi *et al*. (1995) also reported that requirement of heat units decreased for different phenological stages with delay in sowing.

Table 14. Effect of variety and date of sowing on GDD of wheat at maturity at Dhikurpokhari, Kaski, Nepal, 2014/15

Cultivar	November 15	November 30	% reduction due to delay sowing
Farmer's Local	1653.95^{b}	1556.40^{c}	5.89
WK-1204	1735.90^{a}	1705.96^{a}	1.22
Annapurna-4	1711.52^{a}	1637.57^{b}	4.32
Gautam	1719.83^{a}	1651.26^{b}	3.98

Treatments means followed by common latter (s) within column are not significantly different based on DMRT at 0.05% significant level, CT=conventional tillage; ZT-zero tillage.

4.5.2 Heat use efficiency (HUE)

From the results (Table 15) it was observed that all the cultivars used heat more efficiently at normal growing condition compared to late growing condition. Under normal growing condition WK-1204 had significantly highest HUE (1.88) followed by other three cultivars At the late growing condition all the cultivars significantly reduced their HUE at various magnitude compared to normal growing condition. This reduction was lower for Annapurna-4 followed by WK-1204. However, late condition again the cultivar WK-1204 attained highest HUE (1.81), whereas, cultivar Gautam showed the lowest heat use efficiency (1.41). All the cultivars used heat more efficiently under normal growing condition than those of late growing condition. Similar results were reported by Rajput *et al*. (1987), Paul and Sarker (2000), Sikder *et al* (2009), and Chakravarty *et al*. (1984). The normal growing plants produced higher grain yield by using accumulated heat units efficiently. As the temperature was favorable throughout normal growing condition, it accumulated heat more efficiently and increased physiological activities that confirmed higher grain yield.

Table 15. Effect of variety and date of sowing on HUE of wheat at maturity at Dhikurpokhari, Kaski, Nepal, 2014/2015

Cultivar	Heat Use Efficiency		% reduction	Grain Yield ton/ha		% reduction
	November 15	November 30		November 15	November 30	
Farmers local	1.66	1.58	4.41	2.75	2.46	10.42
WK-1204	1.88	1.81	3.7	3.26	3.07	5.57
Annapurna-4	1.72	1.70	1.16	2.91	2.81	4.09
Gautam	1.48	1.41	4.7	2.55	2.33	8.56

4.5.3 Phenothermal index (PTI)

Phenothermal indices (PTI) at maturity of four wheat cultivars (Table 16) showed non-significant influence by the combination of growing conditions and cultivars. However under normal growing condition, all the cultivars had lower PTI at maturity and all cultivars showed higher phenothermal index on late sowing compared to normal growing condition. Similar results were reported by Rajput *et al*. (1987).

Table 16. Effect of variety and date of sowing on PTI of wheat at maturity at Dhikurpokhari, Kaski, Nepal, 2014/15

Cultivar	November 15	November 30
Farmers local	11.23	11.44
WK-1204	11.08	11.28
Annapurna-4	11.24	11.28
Gautam	11.16	11.25

4.6 CSM-CERES-Wheat model

4.6.1 Model calibration

Genetic coefficients of four wheat cultivars (Farmer's Local, WK-120, Annapurna-4 and Gautam) which had already been selected for the statistical sanalysis of the present research was determined by the process of model calibration. The data sets for the four wheat cultivars as zero tillage+ Farmer's local variety+ November 15 sowing, zero tillage+ WK-1204+ November 30 sowing, zero tillage+ Annapurna-4+ November 15 sowing, and zero tillage+Gautam variety+ November 15 sowing were used to determine the genetic coefficient of the wheat cultivars under study by using the CSM-CERES-Wheat model.

The meaning of the various genetic coefficients for wheat cultivars were presented as below;

P1V : Days, optimum vernalizing temperature required for vernalizaion
P1D : Photoperiod response
P5 : Grain filling (excluding lags) phase duration
G1 : Kernel number per unit canopy weight at anthesis
G2 : standard kernel size under optimum conditions
G3 : standard, non-stressed mature tiller wt (including grains) (wt dwt)
PHINT : Interval between successive leaf tip appearance (^{0}C.d)

For the estimation of genetic coefficients for all four wheat cultivars, an ecotype RA001 and ecotype coefficient of RA0014, RA0015, RA0016 and RA0017 were used for farmer's local, WK-120, Annapurna-4 and Gautam respectively. These genetic coefficients were then used for validation of the model.

The genetic coefficients for four wheat varieties were adjusted until there was a match between the observed and simulated dates of anthesis, physiological maturity and grain yield. Appendix 19, 20, 21, 22 presents the details of the runs for the calibrating anthesis, Physiological maturity and grain yield of Farmer's Local, WK-1204, Annapurna-4 and Gautam variety of wheat respectively. Model was run for many times with different possible changes in the values for genetic coefficients, until anthesis, physiological maturity dates and grain yield were perfectly calibrated.

Table 17. Genetic Coefficient of different wheat varieties

Cultivars	P1V	P1D	P5	G1	G2	G3	PHINT	Simulated values		
								A	PM	GY
Farmer's Local	1.0	18	250	50	23	0.7	46	113	147	3000
WK-1204	3.0	39	315	40	71	0.9	64	119	152	3556
Annapurna-4	2.0	15	290	40	55	0.5	72	113	149	3498
Gautam	4.0	10	350	50	33	1.0	40	112	153	2971

Measured values;

Farmer’s Local : A – 113 days, PM – 147 days and GY – 3000 kg/ha
WK-1204 : A – 118 days, PM – 152 days and GY – 3556 kg/ha
Annapurna-4 : A – 114 days, PM –149 days and GY – 3500 kg/ha
Gautam : A – 112 days, PM – 153 days and GY – 2970 kg/ha

4.6.2 Validation of the model

The CERES-Wheat model was tested and validated by using the above determined genetic coefficients of four wheat varieties. Model was validated using treatments except those used for model calibration for all wheat varieties. Observation on anthesis and physiological maturity dates, grain yield, and maximum leaf area index were used for the model validation. Predicted grain yield was well agreed with observed yield (RMSE=779.09, d-stat =0.59). Similarly, close agreement was observed between measured and simulated anthesis date (RMSE=3.73 d-Stat =0.80), physiological maturity dates (RMSE =3.189, d-stat=0.923) and maximum leaf area index (RMSE=2.485 d-Stat=0.536). These 1mvalidation results showed that the CERES-wheat model could be safely used as a tool for simulation of different agronomic and climate change parameters under western mid hills condition.

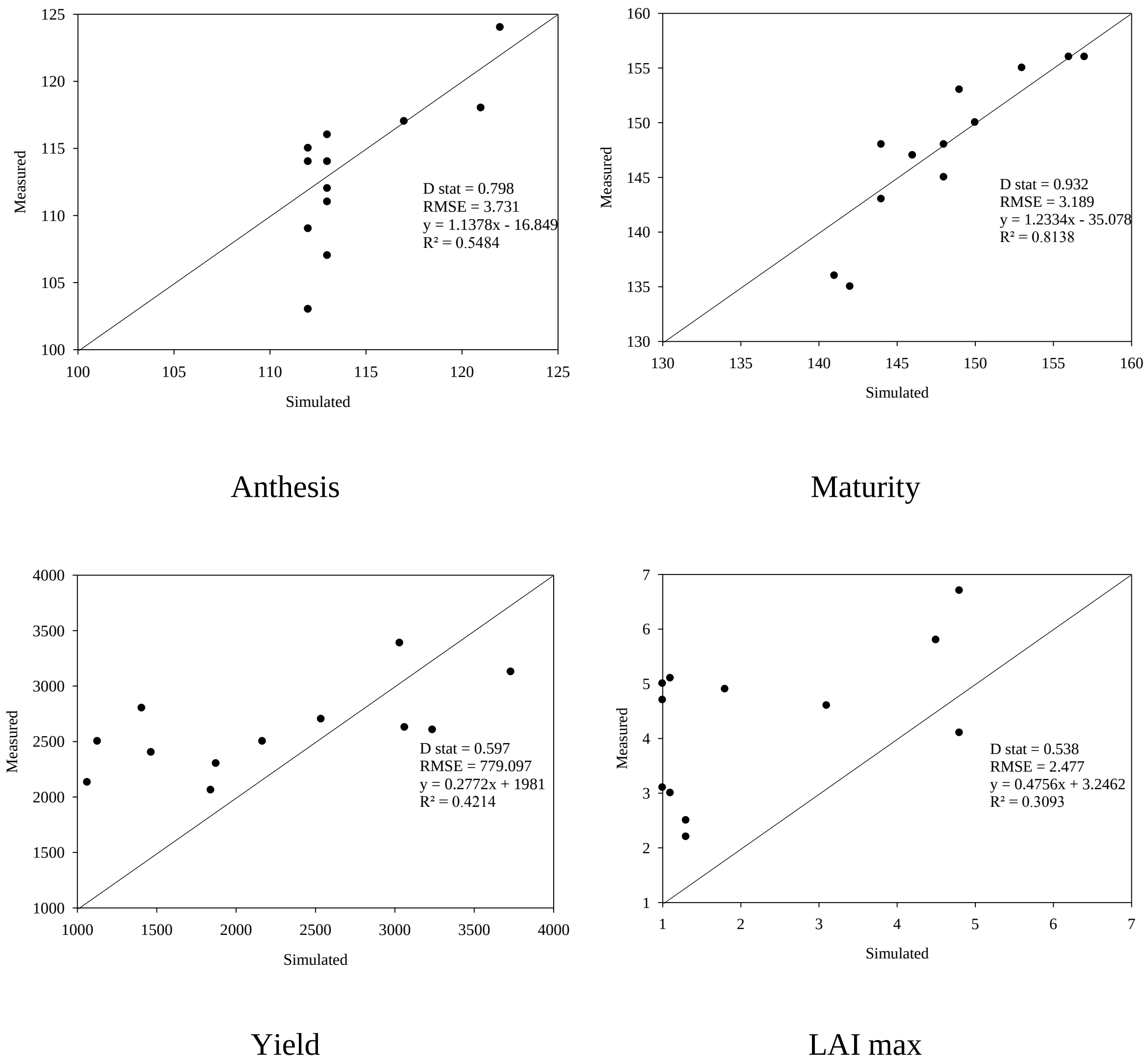

Figure 13. Simulated and measured anthesis, maturity days, yield and maximum leaf area index for farmer's local, WK-120, Annapurna-4 and Gautam

4.6.3 Sensitivity analysis

CERES-Wheat was run for to study sensitivity analysis to different weather years, nitrogen management and climate change scenarios. For this farmer's Local under ZT on November 30 sowing date and WK-1204, Annapurna-4 and Gautam under CT on November 30 sowing date were used.

4.6.3.1 Sensitivity to weather years

CERES-Wheat was run for the standard treatment using 4 years of weather data (2014/15, 2012/13, 2006/07 and 2001/02) (Table 18, Figure 17, 18, 19). The simulated yields were sensitive to various weather years. It was revealed that there was 10, 23 and 44% yield declined in Farmer's Local, WK-1204, Annapurna-4 respectively in the year of 2012/13, where as for Gautam, yield increased was observed about 10% for same year (Table 18).

It was revealed that there was 19, 13 and 9% yield declined in Farmer's Local, WK-1204, Gautam respectively in the year of 2006/07, whereas for Annapurna-4, yield increased was observed about 3% for same year (Table 18). In 2001/02 increased yield 31, 53, 83% was observed in WK-1204, Annapurna-4 and Gautam respectively, where as for Farmer's Local, yield decreased was observed about 1% for same year which was lower in comparison of other years (Table 18). It was found that average temperature was lower in the year of 2001/02, which increased maturity days of Farmer's Local, WK-1204, Annapurna-4 and Gautam. Similarly Rainfall and Solar radiation was highest in 2001/02 which resulted in highest yield. Singh and Ritchi (1993) reported that decreased temperature increase yield significantly.

Table 18. Sensitivity of simulated yield and phenology of wheat cultivars to weather years

	Weather years	Simulated yield (kg ha^{-1})	Percent yield	Anthesis (days)	Physiological maturity (days)
Farmer's Local	20014/15[a]	3063	100	113	142
	2012/13	2771	90	110	138
	2006/07	2480	81	107	136
	2001/02	3033	99	115	145
WK-1204	20014/15[a]	2743	100	117	150
	2012/13	2122	77	114	147
	2006/07	2379	87	115	148
	2001/02	3602	131	126	159
Annapurna-4	20014/15[a]	2167	100	112	144
	2012/13	1215	56	110	140
	2006/07	2232	103	113	146
	2001/02	3313	153	116	157
Gautam	20014/15[a]	1842	100	112	148
	2012/13	1018	110	110	145
	2006/07	1663	91	113	149
	2001/02	3368	183	116	152

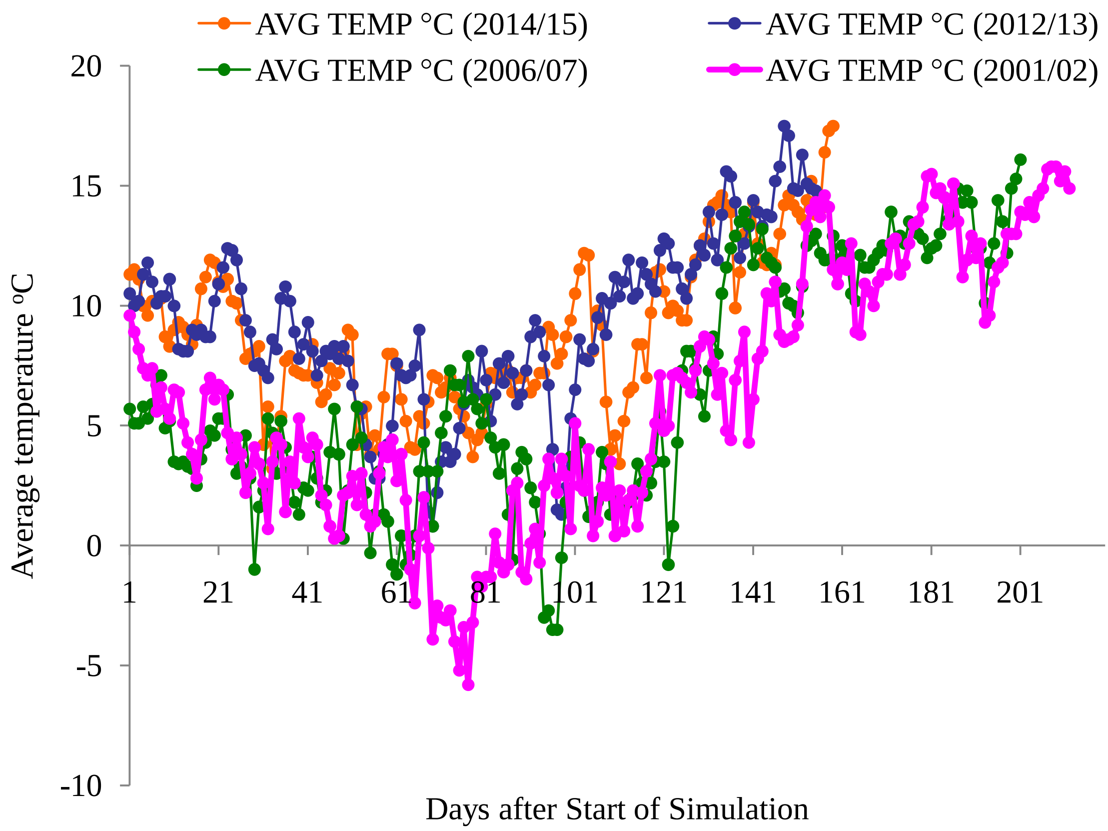

Figure 14. Daily average temperature (^{0}C) during wheat season

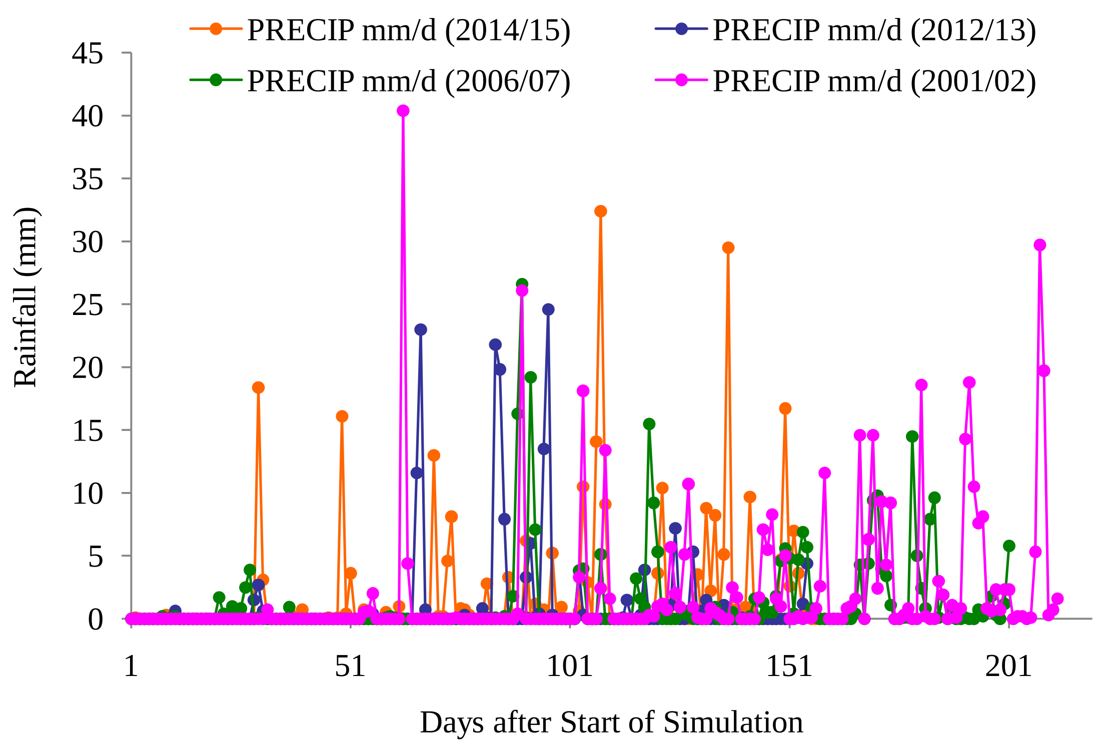

Figure15. Daily rainfall (mm) during wheat season

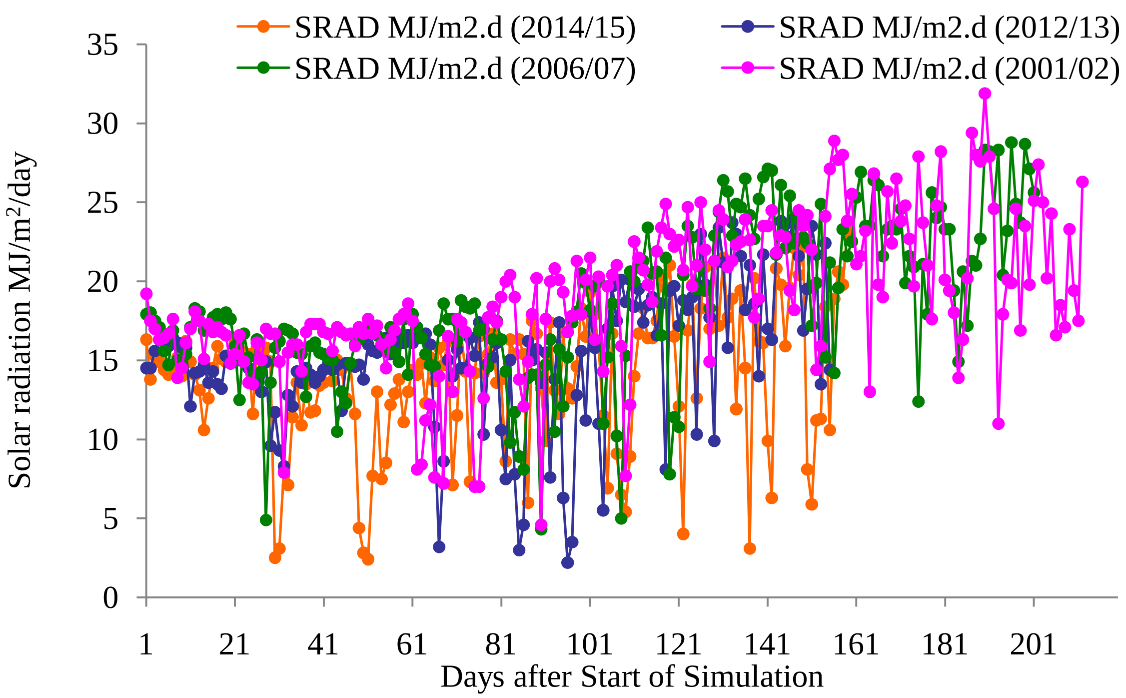

Figure 16. Daily solar radiation (MJ/m^2/day) during wheat season

4.6.3.2 Sensitivity to nitrogen amount

sSensitivity of grain yield and different nitrogen levels was investigated (Table 18). In all the levels of nitrogen, application was spited twice, half at basal and remaining half at 30 DAS. The simulated yields were sensitive to various levels of nitrogen. N stressed in Farmer's Local, WK-120, Annapurna-4 and Gautam resulted yield reduction by 68, 75, 75 and 79%. The result was in conformity with Amgain and Timsina (2008) who reported simulated yield reduction by 46% by reducing level of N from 120 to 0 kg ha^{-1} at PAU soil. Plant growth is adversely affected due to deficiency of nitrogen as it restricts the formation of enzymes, chlorophyll and proteins necessary for growth and development (Reddy and Reddy, 2009). N level of 120 kg ha^{-1} showed increase in the yield in Farmer's Local, WK-1204, Annapurna-4 and Gautam by 8, 3, 3 and 5% respectively. N level of 40 kg ha^{-1} showed decrease in the yield in Farmer's Local, WK-1204, Annapurna-4 and Gautam by 42, 22, 5 and 17% respectively. The result was in line with Sharma *et al.* (2000) who observed that the application of 120kgN/ha gave significantly higher grain yield (4.82 ton/ha). Since wheat was sown rainfed, the recommended nitrogen of 80kg/ha when increased to 120kg/ha could not show major changes in yield. The water limited condition might have hindered the uptake of N even at higher dose of N application.

Table 19. Sensitivity of simulated yield and phenology of wheat cultivars to level of nitrogen

Levels of nitrogen (kg N ha^{-1})	Variety	Simulated yield (kg ha^{-1})	Percent change
0	Farmer's local	990	32
	Wk-1204	686	25
	Annapurna-4	538	25
	Gautam	391	21
40	Farmer's local	1080	58
	Wk-1204	2425	88
	Annapurna-4	2062	95
	Gautam	1538	83
80[a]	Farmer's local	3063	100
	Wk-1204	2743	100
	Annapurna-4	2167	100
	Gautam	1842	100
120	Farmer's local	3505	108
	Wk-1204	2823	103
	Annapurna-4	2228	103
	Gautam	1937	105

4.6.3.3 Effect of Climate Change

Various scenarios of temperature, carbon dioxide concentration and solar radiation were selected for running sensitivity analysis of yields simulated by CERES-Wheat for each cultivar (Table 20). Compared to simulated yield of standard treatment, the decrease in yield was 32, 74, 78 and 71 for Farmer's local, WK-120, Annapurna-4 and Gautam, respectively with the increase in both maximum and minimum temperature by 4^oC but decrease in both maximum and minimum temperature by 4^oC yield was increased by 25, 53, 74, and 112% for Farmer's Local, WK-1204, Annapurna-4 and Gautam, respectively. Elevated CO_2 by 20 ppm along with increased temperature had resulted in decrease in grain yield by 31, 74, 78 and 70%, respectively for Farmer's local, WK-120, Annapurna-4 and Gautam. But, in combination with decreased temperature, there was increased in yield by 26, 54, 75 and 112%, respectively for Farmer's local, WK-120, Annapurna-4 and Gautam. Simulated grain yield was found to be decreased by 29, 72, 78 and 68%, respectively for Farmer's local, WK-120, Annapurna-4 and Gautam 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 34, 75, 79 and 72% for Farmer's local, WK-1204, Annapurna-4 and Gautam, 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), changes in solar radiation amount (1 MJ m^{-2} day^{-1}) had increased the simulated yield of three cultivars.

Yield was increased by 28, 61, 79 and119%, respectively for Farmer's local, WK-120, Annapurna-4 and Gautam for 1 MJ m^{-2} day^{-1} increase in solar radiation and by 23, 44, 63 and 99%, respectively for Farmer's local, WK-120, Annapurna-4 and Gautam for 1 MJ $m^{-2}day^{-1}$ decrease in solar radiation.

Under increased temperature condition (along with elevated CO_2 and increased or decreased solar radiation), the growth duration of wheat 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

20). Temperature primarily affected growth duration with lower temperature increasing the length of time that the crop could intercept radiation.

Table 20. Sensitivity analysis of wheat cultivars with changes in temperature, solar radiation and CO_2 concentration

Max temp (^oC)	Min temp (^oC)	CO_2 conc. (ppm)	Solar radiation ($MJm^{-2}day^{-1}$)	Treatments	Simulated yield (kg ha^{-1})	% yield change	Growth duration (days)
+0[a]	+0	390	+0	Farmer's Local	3063	100	142
				WK-1204	2743	100	150
				Annapurna-4	2167	100	144
				Gautam	1822	100	148
+4	+4	390	+0	Farmer's Local	2063	67	113
				WK-1204	698	25	121
				Annapurna-4	461	21	123
				Gautam	533	29	118
-4	-4	390	+0	Farmer's Local	3844	125	182
				WK-1204	4210	153	188
				Annapurna-4	3736	174	196
				Gautam	3891	211	187
+4	+4	+20	+0	Farmer's Local	2111	69	113
				WK-1204	712	26	121
				Annapurna-4	472	22	123
				Gautam	543	30	118
-4	-4	+20	+0	Farmer's Local	3858	126	182
				WK-1204	4221	154	188
				Annapurna-4	3750	175	196
				Gautam	3923	212	187
+4	+4	+20	+1	Farmer's Local	2169	71	113
				WK-1204	761	28	121
				Annapurna-4	481	22	123
				Gautam	592	32	118
+4	+4	+20	-1	Farmer's Local	2008	66	113
				WK-1204	678	25	121
				Annapurna-4	472	21	123
				Gautam	507	28	118
-4	-4	+20	+1	Farmer's Local	3914	128	182
				WK-1204	4423	161	188
				Annapurna-4	3874	179	196
				Gautam	4036	219	187
-4	-4	+20	-1	Farmer's Local	3771	123	182
				WK-1204	3944	144	188
				Annapurna-4	3530	163	196
				Gautam	3672	199	187

Amgain *et al*. (2006) reported that increase in minimum and maximum temperature by 4^{o}C over the base scenario decreased the wheat yield by 4%. Reduction of minimum and maximum temperature by 4^{0}C and increase in CO_2 by 20 ppm showed increase in yield (Amgain *et al*., 2006). Increased CO_2 concentration and increased temperature increased growth duration and yield, while increased temperature shortened growth duration and reduced leaf area, biomass and yield (Qureshi and Iglesias, 1994); Timsina *et al*, 1997). At elevated CO_2, light intensity positively affects photosynthesis and increased temperature promotes both photosynthesis and leaf area as reported by Imai & Murata (1979). The increased temperature and reduced solar radiation decreased the net photosynthetic active radiant (PAR) interception. The less interception of PAR caused lower assimilate formation in wheat and produced lower yield under increasing temperature and reduced light which was reported by Amgain *et al*. (2006). Increasing temperatures reduced growth duration, and probably decreased photosynthesis, increased water use, and reduced water use efficiency as reported by Imai (1988). Increased CO_2 concentration and decreased temperature increased growth duration and yield, while increased temperature shortened growth duration and reduced leaf area, biomass and yield (Timsina *et al*., 1997; Rao and Sinha, 1994; Qureshi and Iglesias, 1994).

5 SUMMARY AND CONCLUSIONS

5.1 Summary

A field study was carried out in winter season of 2014/15 at the farmer's field of, Dhikurpokhari VDC of Kaski to evaluate the CSM-CERES-Wheat ver. 4.5 for its ability to simulate the growth, phenology, agronomic and climate change parameter of wheat cultivars under different establishment methods and sowing dates. The experiment was conducted in strip-split plot design. Soil of experimental field was loamy sand in texture with medium levels on initial content of N, P and K in surface horizon and lower levels in sub surface horizon. There were altogether sixteen treatment comprising two establishment methods: zero tillage and conventional tillage, four wheat varieties: Farmer's Local, WK-1204, Annapurna-4 and Gautam and two sowing dates: November 15 and November 30 with three replications.

Tillage, varieties and sowing dates had significant *effect on grain* yield, Straw yield and harvest index. Highest *grain* yield, Straw yield and harvest index were observed in November 15 sowing date. Grain Yield and straw yield were highest for WK-1204 whereas HI of WK-1204 and Annapurna-4 were statistically similar. Grain Yield and straw yield were highest for November 15 sowing date whereas HI of November 15 and November 30 was statistically similar.

Interaction effects of tillage, varieties and sowing dates had significant *effect on grain* yield. Grain yield of WK-1204 at both sowing dates and Annapurna-4 were statistically similar. In Other varieties in early sowing (November 15) higher yield was observed whereas delay sowing (November 15) resulted in reduction of yield. There was significant positive correlation between dry matter accumulation and grain yield (R^2=0.28).

LAI, dry matter accumulation and plant height showed significant difference for establishment methods, varieties and sowing dates. Number of tillers per meter ^{2} showed significant difference for varieties and sowing dates. Plant height, LAI and dry matter accumulation were the highest for ZT. Among varieties LAI and DM accumulation were the highest for WK-1204 whereas plant height was the highest for Farmer's Local. November 15 sowing dates produced the highest plant height, DM accumulation, LAI and tiller numbers m^{-2}. There was positive correlation between maximum LAI and grain yield (R^2=0.33).

Effective tillers m^{-2} and spike wt showed significant difference due to tillage. Higher effective tillers and spike weight was observed in ZT whereas effective tillers m^{-2} and filled grains spike^{-1} were non-significant due to variation on sowing dates. Other yield attributing characters showed non-significant difference with tillage, whereas major yield attributing characters showed significant difference with varieties. Effective tillers m^{-2} and filled grains spike^{-1} were the highest for WK-1204 whereas test wt and spike wt were highest for Annapurna-4 and sterility % was highest for Farmer's Local. Spike length of WK-1204, and Gautam was statistically at par. Spike wt. spike length and test weight were highest for November 15 sowing date. There was positive correlation between effective tillers m^{-2} and grain yield (R^2=0.43). Similarly filled grains spike^{-1} also showed correlation between for grain yield (R^2=0.38)

GDD requirement and HUE was the highest for WK-1204 variety. For all varieties November 15 sowing date required higher GDD and HUE than November 30 Showing. Difference in HUE and grain yield due to delay sowing was lower in and Annapurna-4 (1.16% and 4.09%) followed by WK-1204 (3.7%and 5.57%) respectively indicating stable wheat cultivar for staggered wheat planting. PTI was higher in November 30 in all varieties, which denotify late planting is not feasible in wheat.

For evaluation of CSM-CERES-Wheat model, DSSAT ver. 4.5 was used at Dhikurpokhari condition. Model calibration was done using best treatments (ZT practices with four wheat varieties under two sowing dates: Farmer's Local on November 15, WK-1204 on November30, Annapurna-4 on November 15 and Gautam on November 15). 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 Farmer's Local were: 1 (P1V), 18 (P1D), 250 (P5), 50 (G1), 23 (G2), 0.7(G3) and 46 (PHINT). For WK-1204 it was 3 (P1V), 39 (P1D), 315 (P5), 40 (G1), 71 (G2), 0.9 (G3) and 64 (PHINT). Similarly, genetic coefficient for Annapurna-4: 2 (P1V), 15 (P1D), 290 (P5), 40 (G1), 55 (G2), 0.5 (G3) and 72 (PHINT) and for Gautam it was 4 (P1V), 10 (P1D), 350 (P5), 50 (G1), 33 (G2), 1.0 (G3) and 40 (PHINT).

The CERES-Wheat model was tested and validated by using the above determined genetic coefficients of four varieties under different tillage and sowing dates except those which were used for model calibration. Observation result on days to anthesis (RMSE=3.731 d-Stat = 0.798) and physiological maturity dates (RMSE=3.189, d-stat=0.923), grain yield (RMSE=734.299, d-stat=0.631), and maximum leaf area index (LAI) (RMSE=2.485, d-stat=0.536) were found to be suitable as the indicator of perfect validation. Those RMSE and d-stat value showed that the CERES-Wheat model can be safely used as a tool for sensitivity analysis under mid western hill of Kaski.

By running sensitivity analysis, the model was found sensitive to weather years, applied N and various parameters of climate change. In the 2012/13 and 2006/07, decrease in yield was observed. In the year 2001/2002 increased yield was found with increasing crop duration. Nitrogen stress in Farmer's Local, WK-120, Annapurna-4 and Gautam resulted significant yield reduction. *With increasing dose of Nitrogen level from 0 to 40 there was lesser reduction of yield. N level 120 kg/ha resulted lesser increase in yield.*

Increase in minimum and maximum temperature by 4^{o}C decreased the wheat yield whereas decrease of temperature by same amount increase the yield in all wheat varieties.Change in temperature (-4^{0}C), CO_2 concentration (+20 ppm) with change in solar radiation (-MJ m^{-2} day^{-1}) resulted increase in crop duration and maximum increase in yield of Farmer's Local, WK-120, Annapurna-4 and Gautam by 28, 61, 79 and 119%. Similarly change in temperature (+4^{0}C), CO_2 concentration (+20 ppm) with change in solar radiation (+MJ m^{-2} day^{-1}) resulted decrease in crop duration and maximum decrease in yield by 34, 72, 78 and 68% respectively.

5.2 Conclusion

To achieve the higher production of the wheat, WK-1204 variety could be sown under ZT around November 15. For other varieties (Farmer's Local, Annapurna-4 and Gautam) higher yield could be obtained only when sowing done on November 15 under ZT obtain higher yield sowing should be done in November 15 under ZT and under CT sowing can be delayed up to November 30. The calendar days, GDD, HUE and PTI are better agro-climatic indices to predict the yield and phenology of wheat. Similarly CSM-CERES-Wheat embedded under DSSAT ver. 4.5 can be rigorously used to predict the agronomic management options and climate change scenarios at subtropical agro-climatic conditions of mid-western hill conditions.

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APPENDICES

Appendix 1. Weather conditions during crop growing season in 2014/15 at Dhikurpokhari VDC, Kaski District, Nepal

Months	Min temp.(^oC)	Max. temp.(^oC)	Rainfall (mm)	Relative humidity
November	16.1	5.93	1.3	51.95
December	13.76	3.06	22.9	46.85
January	12.25	0.59	50.2	53.85
February	14.70	2.31	48.8	51.20
March	16.25	4.07	116.1	60.31
April	20.11	8.47	89.10	56.70

Appendix 2. Mean sum of square from ANOVA of effective tillers m^{-2} at harvest, grain yield, straw yield and harvest index of wheat at Dhikurpokhari VDC, Kaski, District, Nepal, 2014/15

Source	df	Effective	Grain yield	Straw yield	Harvest

		tiller/m^2 at harvest			index
Replication	2	69.64	0.014	0.013	1.965
Vertical factor A	1	10384*	5.427**	1.297**	1.54**
Error a	2	258.14	0.014	0.013	1.965
Horizontal factor B	3	13141.41**	1.053**	0.467**	39.906**
Error b	6	541.22	0.031	0.018	1.381
AB	3	3916.97**	0.106	0.355**	29.147**
Error c	6	175.78	0.031	0.018	1.381
Subplot factor C	1	6.75	0.276**	0.067*	8.996
AC	1	6120.08**	0.085*	0.158**	0.418
BC	3	168.30	0.058	0.068*	5.528
ABC	3	151.19	0.075*	0.041	1.755
Error(d)	16	239.35	0.019	0.016	2.431
Total	47				

Appendix 3. Mean sum of square from ANOVA of spike weight, spike length, filled grains spike^{-1}, sterility % and test weight of wheat at Dhikurpokhari VDC, Kaski District, Nepal, 2014/15

Source	df	Spike weight	Spike length	Filled grains spike^{-1}	Sterility %	Test weight
Replication	2	0.018	0.029	31.68	0.038	11.025
Vertical factor A	1	0.295*	0.123	99.18	11.408*	12.393
Error (a)	2	0.007	0.389	10.93	0.27	1.494
Horizontal factor B	3	1.766**	11.527**	172.07**	195.90**	606.603**
Error (b)	6	0.042	0.696	17.41	0.625	3.259
AB	3	0.189**	1.60*	118.96*	16.929**	0.884
Error(c)	6	0.012	0.332	23.38	0.657	1.81
Subplot factor C	1	0.986**	1.107*	31.68	34.949**	32.193**
AC	1	0.166*	0.306	9.18	5.096	0.523
BC	3	0.259**	0.257	49.68	3.193	3.787
ABC	3	0.037	0.249	5.63	9.484**	0.292
Error(d)	16	0.038	0.179	18.41	1.20	2.326
Total	47					

Appendix 4. Mean sum of square from ANOVA of plant height of wheat at different growth stages at Dhikurpokhari VDC, Kaski District, Nepal, 2014/15

		Days After Sowing (DAS)					
Source	df	30	45	60	75	90	120
Replication	2	0.981	7.802	5.803	12.546	18.903	6.156
Vertical factor A	1	0.508	53.299	419.255*	950.164*	1017.15*	433.862*
Error(a)	2	2.084	8.527	16.292	27.546	27.239	9.528
Horizontal factor B	3	80.4**	161.5**	1000.3**	2452.5**	3349.5**	2121.5**
Error(b)	6	3.907	6.179	8.881	9.382	12.054	9.255
AB	3	1.185	7.782*	21.20**	30.037	103.815**	86.386**
Error (c)	6	2.532	1.398	1.996	6.953	6.012	5.529
Subplot factor C	1	56.89**	77.77**	37.70*	737.58**	67.92**	377.94**
AC	1	2.21	84.854**	308.155**	0.288	652.540**	0.502*
BC	3	1.474	32.163**	53.901**	21.417	83.701**	11.715
ABC	3	5.074	29.561**	1.567	23.565*	26.559*	11.723
Error(d)	16	2.584	4.103	4.749	7.118	5.446	17.380
Total	47						

Appendix 5. Mean sum of square from ANOVA of Leaf area index of wheat at different sowing dates at Dhikurpokhari VDC, Kaski District, Nepal, 2014/15

Source	df	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Replication	2	0.000	0.021*	0.069	0.069	0.164
Vertical factor A	1	0.201**	1.531**	9.405*	19.080**	22.35**
Error(a)	2	0.002	0.00	0.147	0.155	0.033
Horizontal factor B	3	0.071**	2.128**	7.567***	1.321**	4.650**
Error(b)	6	0.001	0.000	0.129	0.031	0.123
AB	3	0.038**	0.985**	1.090**	6.768**	3.871**
Error (c)	6	0.001	0.002	0.086	0.025	0.059
Subplot factor C	1	0.028**	1.293**	2.189**	11.528**	9.550**
AC	1	0.112**	0.369**	0.358	1.095**	2.099**
BC	3	0.008*	0.153**	0.185	1.578**	0.413*
ABC	3	0.010**	0.014**	0.240	1.176**	3.105**
Error(d)	16	0.002	0.001	0.124	0.127	0.104
Total	47					

Appendix 6. Mean sum of square from ANOVA of above ground dry matter of wheat at different growth stages at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Source	df	30 DAS	45DAS	60 DAS	75 DAS	90 DAS	105 DAS	120 DAS
Replication	2	190	20.2	339.0	363.0	1032.938	197530	4858695
Vertical factor A	1	6486	46625.3**	369076**	9571174**	6327090**	443713	12838
Error(a)	2	1510	5.14	263.8	505.6	999.438	46126	466784
Horizontal factor B	3	7958**	40353**	393648**	1509456**	2233298**	7962106**	11489358**
Error(b)	6	666.2	59	712.021	412.313	1200.8	99438	556071
AB	3	138	36653**	161982**	836534**	1369296**	993486*	634912
Error (c)	6	532.7	31	81.535	863.174	3206.5	118854	950262
Subplot factor C	1	70380**	13200**	67875**	2110085**	4201425**	2817367**	7628088**
AC	1	16502**	65860**	134726**	46376**	120100.0	48070	1079700*
BC	3	314	13821**	143620**	44792**	381988.0**	134543	109597
ABC	3	309	7070**	32872**	177088**	106103.9	160589	197483
Error(d)	16	541	41.75	340.854	1493.438	51175.1	58626	145208
Total	47							

Appendix 7. Mean sum of square from ANOVA of number of tillers m^{-2} square of wheat at different growth stages at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Source	df	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	at harvest
Replication	2	8190	6848.58	5685.250	9956.77*	5630.08	5806.68	90.75
Vertical factor A	1	7252	5611.68	11594.08	22533.33*	48196.68*	43140.02*	23807.52*
Error(a)	2	2309	1770.25	1601.083	519.27	1257.75	1018.16	936.33
Horizontal factor B	3	10506*	13098.96*	9668.77	12813.88*	24609.68*	20339.18*	23973.41**
Error(b)	6	1209	2148.77	2553.11	2368.57	2798.25	3191.27	1410.30
AB	3	4873	7263.02	10628.08*	5738.88	2310.24*	1878.07**	1265.96*
Error (c)	6	3226	1926.83	1712.00	2001.91	245.13	160.78	153.44
Subplot factor C	1	22620**	19723.52**	18644.08**	14352.08**	19240.02**	15732.52**	16837.52**
AC	1	3008	397.52	5.33	168.75	7.521	256.68	652.68
BC	3	799	1964.07	861.86	1663.19	1665.68	2492.79	3041.52**
ABC	3	1046	378.85	801.44	552.08	1363.74	850.29	662.57
Error(d)	16	992	1110.29	1277.54	931.771	540.41	830.75	340.62
Total	47							

Appendix 8. Mean sum of square from ANOVA of phenology of wheat at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Source	df	Heading days	Anthesis days	Physiological maturity days
Replication	2	33.39	89.31	5.89
Vertical factor A	1	54.18	46.02	58.52
Error a	2	8.68	12.27	3.52
Horizontal factor B	3	225.74**	240.91**	336.41**
Error b	6	6.20	6.54	5.95
AB	3	10.576*	6.18	28.41**
Error c	6	2.16	3.18	6.41
Subplot factor C	1	136.68**	123.52**	744.18
AC	1	13.021	9.18	0.021
BC	3	41.52*	40.79*	19.41
ABC	3	9.96	13.68	2.021
Error(d)	16	5.52	4.77	2.938
Total	47			

Appendix 9. Interaction effects of tillage and varieties on Straw yield and HI of wheat at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Treatment	Straw Yield (ton/ha)				Harvest index (%)			
	Variety				Variety			
	Farmers Local	WK-1204	Annapurna-4	Gautam	Farmers Local	WK-1204	Annapurna-4	Gautam
Tillage								
ZT	3.20[d]	3.79[ab]	3.64[bc]	3.14[d]	50.04[a]	51.17[a]	51.01[a]	50.27[a]
CT	3.55[c]	3.90[a]	3.69[bc]	3.95[a]	42.73[b]	43.89[b]	42.30[b]	36.42[c]
LSD $_{(0.05)}$	0.18				1.16			
SEm (±)	0.06				0.38			

Appendix 10. Interaction effects of tillage and sowing date on straw yield and above ground dry matter accumulation of wheat at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Treatment	Straw yield (t ha^{-1})		Above ground dry matter	
	Date of sowing		Date of sowing	
Tillage	Nov 15	Nov 30	Nov 15	Nov 30
ZT	3.54^{b}	3.35^{c}	6535^{b}	6038^{a}
CT	3.75^{a}	3.79^{a}	6868^{a}	5771^{c}
$LSD_{(0.05)}$	0.10		329.8	
SEm(±)	0.03		109.93	

Appendix 11. Interaction effects of tillage and varieties on LAI at 90 DAS and plant height at 120 DAS at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Treatment	LAI at 90 DAS				Plant height at 120 DAS			
	Variety				Variety			
Tillage	Farmers local	WK-1204	Annapurna-4	Gautam	Farmers local	WK-1204	Annapurna-4	Gautam
ZT	6.17^{a}	5.01b	5.03^{b}	4.40^{c}	113.4^{a}	93.64^{b}	89.84^{c}	92.62^{bc}
CT	3.43^{e}	4.98b	3.97^{d}	2.77^{f}	113.8^{a}	89.43^{c}	77.30^{e}	84.57^{d}
$LSD_{(0.05)}$			0.34					
SEm (±)			0.11					

Appendix 12. Interaction effects of varieties and sowing dates on straw yield and LAI at 90 DAS of wheat at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Treatment	Straw yield (t ha^{-1})		LAI at 90 DAS	
	Date of sowing		Date of sowing	
	Nov 15	Nov 30	Nov 15	Nov 30
Variety				
Farmer's Local	3.46^{c}	3.29^{d}	5.15^{a}	4.46^{b}
WK-1204	3.89^{a}	3.8^{a}	5.42^{a}	4.57^{b}
Annapurna-4	3.59^{bc}	3.73^{ab}	5.21^{a}	3.79^{c}
Gautam	3.62^{b}	3.46^{c}	3.89^{c}	3.29^{d}
$LSD_{(0.05)}$	0.15		0.39	
SEm (±)	0.05		0.33	

Appendix 13. Interaction effects of tillage and varieties on length of spike and number of filled grains spike-1 of wheat at Dhikurpokhari VDC of Kaski District, Nepal, 2014/15

Treatment	Length of spike				Number of filled grain per spike			
	Variety				Variety			
	Farmers Local	WK-1204	Annapurna-4	Gautam	Farmers Local	WK-1204	Annapurna-4	Gautam
Tillage								
ZT	7.01^{c}	9.17^{ab}	8.92^{ab}	9.64^{a}	36.33^{abc}	43.33^{a}	37.16^{ab}	36.33^{abc}
CT	7.32^{c}	9.18^{ab}	9.36^{a}	8.74^{b}	30.00^{cd}	37.66^{ab}	35^{bc}	27.66^{d}
$LSD_{(0.05)}$	0.81				5.91			
SEm (±)	0.23				1.97			

Appendix 14. Interaction effects on wt. of spike and sterility % of wheat as influenced by tillage and SD at Dhikurpokhari VDC of Kaski district, Nepal, 2014/15

Treatment	Wt of spike		sterility %	
	Date of sowing		Date of sowing	
Tillage	Nov 15	Nov 30	Nov 15	Nov 30
ZT	2.16^{a}	1.99^{a}	8.95^{c}	10.03^{b}
CT	2.12^{a}	1.77^{b}	9.27^{bc}	11.66^{a}
$LSD_{(0.05)}$	0.16		0.94	
SEm(±)	0.56		0.31	

Appendix 15. Interaction effects of varieties and sowing dates and varieties and tillage on wt. of spike and sterility % of wheat as influenced by tillage and SD at Dhikurpokhari VDC of Kaski District, Nepal, 2014/15

Treatment	Weight of spike		Sterility %		
	Date of sowing		Tillage		
	Nov 15	Nov 30		ZT	CT
Variety			Variety		
Farmer's Local	1.47^{d}	1.50^{d}	Farmer's Local	17.20^{a}	14.67^{b}
WK-1204	2.38^{ab}	1.70^{d}	WK-1204	5.81^{g}	8.30^{de}
Annapurna-4	2.56^{a}	2.27^{b}	Annapurna-4	7.84^{ef}	$9,.81^{c}$
Gautam	2.17^{bc}	1.95^{c}	Gautam	7.10^{f}	9.06^{cd}
$LSD_{(0.05)}$	0.23		1.14		
SEm (±)	0.07		0.33		

Appendix 16. Calibration runs for determination of genetic coefficients of Farmer's Local variety of wheat

Run no.	Genetic Coefficients							Simulated values		
	P1V	P1D	P5	G1	G2	G3	PHINT	A	P	G
1	5	75	320	43	33	4.5	106	142	173	1465
2	15	75	320	43	33	4.5	106	146	176	1448
3	2	75	320	43	33	4.5	106	140	172	1296
4	5	100	320	43	33	4.5	106	162	188	2458
5	5	100	420	43	33	4.5	106	162	193	2464
6	5	100	320	40	33	4.5	86	162	188	3608
7	5	100	320	40	33	4.5	46	160	187	3357
8	2	60	320	40	33	4.5	46	131	165	3167
9	1	30	320	40	23	4.5	46	117	154	2019
10	1	20	320	40	43	4.5	46	117	154	2083
11	1	45	120	40	23	2.5	46	124	145	2779
12	1	45	150	40	23	0.5	46	124	147	2922
13	1	18	150	40	23	0.5	46	113	139	2915
14	1	18	250	40	23	0.5	46	113	147	3123
15	1	18	250	50	23	0.7	46	113	147	3000

Observed: A, Anthesis=113 days; M, Maturity=147 days; G= Grain yield=3000 kg/ha

Appendix 17. Calibration runs for determination of genetic coefficients of WK-1204 variety of wheat

Run no.	Genetic Coefficients							Simulated values		
	P1V	P1D	P5	G1	G2	G3	PHINT	A	P	G
1	3	75	410	26	25	3	95	141	177	1702
2	3	75	410	26	25	3	50	141	177	3894
3	3	55	410	26	25	3	50	129	169	3197
4	3	55	310	26	25	3	50	129	162	3183
5	3	55	310	26	25	1	50	129	162	3325
6	3	65	310	26	25	1	50	134	167	3667
7	3	65	310	26	25	1	45	134	167	3575
8	3	65	310	26	25	1	50	131	160	3187
9	3	39	310	26	25	1	50	131	160	3187
10	3	39	315	26	25	1	50	119	152	3338
11	3	39	315	40	25	1	50	119	152	3362
12	3	39	315	40	71	0.9	50	119	152	3346
13	3	39	315	40	71	0.9	64	119	152	3556

Observed: A, Anthesis=118 days; M, Maturity=152 days; G= Grain yield=3556 kg/ha

Appendix 18. Calibration runs for determination of genetic coefficients of Annapurna-4 variety of wheat

Run no.	Genetic Coefficients							Simulated values		
1	P1V	P1D	P5	G1	G2	G3	PHINT	A	P	G
2	25	83	515	15	44	3.2	100	153	191	2172
3	25	43	515	15	44	3.2	100	131	176	810
4	25	43	215	15	44	3.2	100	131	157	801
5	5	43	215	15	44	3.2	100	125	152	681
6	5	43	115	15	44	3.2	100	125	145	679
7	5	40	115	15	44	3.2	100	124	144	607
8	5	40	115	15	44	2.2	100	124	144	616
9	5	40	115	15	44	2.2	50	124	144	2805
10	5	40	115	15	44	0.5	50	124	144	2933
11	5	40	170	15	75	0.5	50	124	148	2733
12	2	40	170	15	75	0.5	50	122	147	2764
13	2	15	290	15	75	0.5	50	113	149	3197
14	2	15	290	15	55	0.5	72	113	149	3468
15	2	15	290	40	55	0.5	72	113	149	3498

Observed: A, Anthesis=114 days; M, Maturity=149 days; G= Grain yield=3500 kg/ha

Appendix 19. Calibration runs for determination of genetic coefficients of Gautam variety of wheat

Run no.	Genetic Coefficients							Simulated values		
	P1V	P1D	P5	G1	G2	G3	PHINT	A	P	G
1	5	75	320	43	33	4.5	106	142	173	1465
2	5	50	320	43	33	4.5	106	128	161	646
3	5	50	220	43	33	4.5	106	128	155	644
4	5	40	200	43	33	4.5	106	124	150	511
5	5	40	200	43	33	4.5	55	124	150	2520
6	5	40	200	43	33	2.5	55	124	150	2589
7	5	40	200	43	33	1.5	55	124	150	2673
8	5	40	200	43	33	1	55	124	150	2710
9	5	40	200	50	33	1	55	124	150	2710
10	5	30	200	50	33	1	55	119	147	2072
11	5	30	200	50	33	1	48	119	147	2415
12	5	35	250	50	33	1	48	121	152	2741
13	5	35	250	50	33	1	40	122	153	2971
14	4	10	250	50	33	1	40	112	146	2964
15	4	10	350	50	33	1	40	112	153	2971

Observed: A, Anthesis=112 days; M, Maturity=153 days; G= Grain yield=2970 kg/ha

Appendix 20. Minimum data required for calibration and validation of CSM-CERES-Wheat 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 and Bulk density (layer wise)
5. Chemical properties: PH, Organic carbon, total Nitrogen
6. Initial conditions: Information to be taken before crop sowing from field
   - KCl extractable ammonium and nitrate N at various depths
   - Soil moisture content at various depths
   - Date and depth of residue incorporation (material type, amount and n concentration
7. Date of sowing and Emergence
8. Date and Amount of irrigation
9. N fertilizer: Schedule, source and amount, depth and placement of incorporation
10. Phenological events recorded:
    - Emergence
    - Days to anthesis
    - Days to physiological maturity
11. Monitoring and recording of LAI at different stages of growth

12 Recording of dried biomass (tops weight other than root of whole plant) at different stages of growth

13. Yield and its components

Grain yield

- Number of effective tillers per m^{-2}
- Grain number per spike
- Thousand grain weight

Appendix-21 'A' file (TUIA1401.WHA) used for calibration and validation of CERES-Wheat using experiments

*EXP.DETAILS: TUIA1401WH ASSESSMENT OF WHEAT CULTIVARS, TILLAGE AND SOWING DATES
! File last edited on day 12/28/2015 at 2:16:16 PM

@TRNO	HWAM	HWUM	H#AM	H#UM	LAIX	CWAM	BWAM	ADAT	MDAT
1	3000	0.028	7609	40	5.64	6326	3326	15067	15101
2	2626	0.027	6887	32	6.72	5703	3076	15076	15104
3	3386	0.041	7981	36	5.75	7223	3836	15078	15110
4	3556	0.040	9438	39	4.27	7296	3740	15087	15121
5	3500	0.045	7264	35	5.46	7206	3706	15068	15103
6	3126	0.044	8558	38	4.61	6703	3576	15081	15112
7	2970	0.042	6648	36	4.73	6253	3283	15066	15107
8	2603	0.040	7356	36	4.09	5606	3003	15085	15114
9	2500	0.027	6255	33	4.65	6100	3600	15065	15101
10	2300	0.026	3964	26	2.22	5800	3500	15072	15105
11	2800	0.040	11628	44	5.1	6750	3950	15072	15110
12	2700	0.037	10360	42	4.87	6550	3850	15086	15119
13	2400	0.044	6019	34	4.97	5880	3480	15068	15107
14	2500	0.042	5124	35	2.97	6400	3900	15078	15117
15	2130	0.041	4089	28	3.07	6110	3980	15069	15109
16	2060	0.041	3564	26	2.49	5980	3920	15083	15117

Appendix-22. 'T' file (TUIA1401.WHT) including all the treatment details at different time series

```
*EXP.DETAILS: TUIA1401WH ASSESSMENT OF WHEAT CULTIVARS, TILLAGE
AND SOWING DATES!
File last edited on day 12/28/2015 at 2:16:16 PM

@TRNO   DATE  LAID  SWAD  GWAD  LWAD  CWAD  T#AD
     1 14334     0   -99     0   -99     0   329
     1 14349  0.36   -99     0   -99   202   343
     1 14364  0.79   -99     0   -99   274   348
     1 15014  2.93   -99     0   -99  1024   353
     1 15029  4.77   -99     0   -99  2251   313
     1 15044  5.64    99     0   -99  4343   338
     1 15059     0   -99     0   -99  5398     0
     1 15075     0   -99     0   -99  6176     0
     1 15108     0   -99  3000   -99  6326   297
     2 14349     0   -99     0   -99     0   298
     2 14364  0.28   -99     0   -99    85   298
     2 14015  0.46   -99     0   -99   338   323
     2 14029  2.72   -99     0   -99  1310   313
     2 14044  4.73   -99     0   -99  1946   300
     2 14060  6.72   -99     0   -99  3524   312
     2 14075     0   -99     0   -99  5350     0
     2 14090     0   -99     0   -99  5512     0
     2 14108     0   -99  2630   -99  5703   293
     3 14334     0   -99     0   -99     0   371
     3 14349  0.72   -99     0   -99   264   403
     3 14364  2.48   -99     0   -99   408   430
     3 15015  4.35   -99     0   -99  1094   437
     3 15030  5.62   -99     0   -99  3771   447
     3 15045  5.75   -99     0   -99  4918   438
     3 15060     0   -99     0   -99  6636     0
     3 15075     0   -99     0   -99  7531     0
     3 15115     0   -99  3386   -99  7223   387
     4 14349     0   -99     0   -99     0   358
     4 14364   0.5   -99     0   -99   128   332
     4 15014  1.57   -99     0   -99   556   370
     4 15029  4.18   -99     0   -99  1261   383
     4 15044  4.43   -99     0   -99  3038   365
     4 15059  4.27   -99     0   -99  4800   373
     4 15074     0   -99     0   -99  6534     0
     4 15089     0   -99     0   -99  6968     0
     4 14334     0   -99  3566   -99  7296   307
     5 14334     0   -99     0   -99     0   310
     5 14349  0.51   -99     0   -99   234   321
     5 14364  0.96   -99     0   -99   304   354
     5 15014  3.06   -99     0   -99   980   352
     5 15029  5.17   -99     0   -99  2281   361
     5 15044  5.46   -99     0   -99  4288   356
     5 15059     0   -99     0   -99  6035     0
     5 14074     0   -99     0   -99  6751     0
```

5	14108	0	-99	3500	-99	7206	343
6	14349	0	-99	0	99	0	263
6	14364	0.32	-99	0	-99	140	295
6	15014	0.56	-99	0	-99	506	302
6	15029	3.29	-99	0	-99	673	323
6	15044	4.91	-99	0	-99	2009	320
6	15059	4.61	-99	0	-99	3991	315
6	15074	0	-99	0	-99	5606	0
6	15089	0	-99	0	-99	6333	0
6	15118	0	-99	3126	-99	6703	317
7	14334	0	-99	0	-99	0	263
7	14349	0.41	-99	0	-99	198	263
7	14364	0.71	-99	0	-99	243	278
7	15014	2.1	-99	0	-99	584	278
7	15029	5.85	-99	0	-99	2692	277
7	15044	4.73	-99	0	-99	4746	278
7	15059	0	-99	0	-99	5736	0
7	15074	0	-99	0	-99	5681	0
7	15115	0	-99	2970	-99	6253	230
8	14349	0	-99	0	-99	0	243
8	14364	0.3	-99	0	-99	89	263
8	15014	0.33	-99	0	-99	258	255
8	15029	1.25	-99	0	-99	561	277
8	15044	5.63	-99	0	-99	2077	257
8	15059	4.73	-99	0	-99	4012	263
8	15074	0	-99	0	-99	4930	0
8	15089	0	-99	0	-99	5336	0
8	15123	0	-99	2603	-99	5606	220
9	14334	0	-99	0	-99	0	318
9	14349	0.24	-99	0	-99	143	331
9	14364	0.67	-99	0	-99	228	312
9	15014	2.17	-99	0	-99	682	335
9	15029	3.39	-99	0	-99	1850	298
9	15044	4.65	-99	0	-99	3270	315
9	15059	0	-99	0	-99	5282	0
9	15074	0	-99	0	-99	6573	0
9	15108	0	-99	2500	-99	6100	293
10	14349	0	-99	0	-99	0	213
10	14364	0.29	-99	0	-99	110	248
10	15014	0.5	-99	0	-99	234	265
10	15029	1.97	-99	0	-99	827	255
10	15044	2.79	-99	0	-99	1073	220
10	15059	2.22	-99	0	-99	2738	247
10	15074	0	-99	0	-99	4551	0
10	15089	0	-99	0	-99	5360	0
10	15108	0	-99	2300	-99	5800	235
11	14334	0	-99	0	-99	0	330
11	14349	0.24	-99	0	-99	196	337
11	14364	1.02	-99	0	-99	286	340
11	15014	3.33	-99	0	-99	1004	338
11	15029	5.75	-99	0	-99	1776	335
11	15044	5.1	-99	0	-99	4021	338
11	15059	0	-99	0	-99	6975	0
11	15074	0	-99	0	-99	8074	0
11	15115	0	-99	2800	-99	6750	323

12	14349	0	-99	0	-99	0	280
12	14364	0.39	-99	0	-99	149	282
12	15014	0.6	-99	0	-99	334	287
12	15029	0.09	-99	0	-99	762	288
12	15044	2.42	-99	0	-99	1736	280
12	15059	4.29	-99	0	-99	3769	285
12	15074	0	-99	0	-99	6262	0
12	15089	0	99	0	-99	7544	0
12	15123	0	-99	2700	-99	6550	243
13	14334	0	-99	0	-99	0	280
13	14349	0.36	-99	0	-99	180	293
13	14364	0.7	-99	0	-99	352	283
13	15014	2.21	-99	0	-99	840	292
13	15029	5.2	-99	0	-99	1824	282
13	15044	4.97	-99	0	-99	4725	286
13	15059	0	-99	0	-99	6430	0
13	15074	0	-99	0	-99	7091	0
13	15108	0	-99	2400	-99	5880	292
14	14349	0	-99	0	-99	0	250
14	14364	0.3	-99	0	-99	130	267
14	15014	0.65	-99	0	-99	272	263
14	15029	1.52	-99	0	-99	584	287
14	15044	2.86	-99	0	-99	1570	257
14	15059	2.97	-99	0	-99	4075	269
14	15074	0	-99	0	-99	6358	0
14	15089	0	-99	0	-99	6007	0
14	15118	0	-99	2500	-99	6400	247
15	14334	0	-99	0	-99	0	310
15	14349	0.24	-99	0	-99	137	313
15	14364	0.42	-99	0	-99	410	325
15	15014	1.89	-99	0	-99	880	279
15	15029	2.66	-99	0	-99	1725	233
15	15044	3.07	-99	0	-99	3774	285
15	15059	0	-99	0	-99	4902	0
15	15074	0	-99	0	-99	5732	0
15	15113	0	-99	2130	-99	6110	200
16	14349	0	-99	0	-99	0	258
16	14364	0.3	-99	0	-99	110	293
16	15014	0.44	-99	0	-99	273	313
16	15029	1.29	-99	0	-99	507	278
16	15044	2.5	-99	0	-99	1367	228
16	15059	2.49	-99	0	-99	2440	273
16	15074	0	-99	0	-99	4227	0
16	15089	0	-99	0	-99	4170	0
16	15123	0	-99	2060	-99	5980	204

Appendix: 23. ‘S’ file (TUIA14001.SOL) used in CERES-Wheat model representing the chemical and physical properties of soil under experiment in Dhikurpokhari, Kaski

```
*TUIA140001  -99         SL      100 Sandy loam top
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 KASKI       Nepal           28.28   83.85 Spodosol
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN   .13     6    .4    73     1     1 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    20   -99  .129  .333  .394     1  2.59  1.48  3.09   3.7  47.9   -99   .27   6.2   -99   -99   -99
    40   -99  .132  .312  .449  .549  1.32  1.36  1.82  11.3  48.7   -99   .15   6.4   -99   -99   -99
    60   -99  .118  .296  .446  .368  1.32  1.37  1.67   9.4  49.6   -99   .15   6.4   -99   -99   -99
    80   -99  .133  .306  .418  .247  1.32  1.45  1.47  13.4    49   -99   .12   6.8   -99   -99   -99
   100   -99  .123  .284   .39  .165  1.32  1.53  1.32  12.3  44.8   -99   .11     7   -99   -99   -99
```

Appendix-24. 'W' file (IAAS1401.WTH) used for running experimental files in CERES-Wheat for Dhikurpokhari, Kaski

```
*WEATHER DATA : SRIJ

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  SRIJ   28.280   83.850   900  11.1   6.9   2.0  10.0
@DATE  SRAD  TMAX  TMIN  RAIN  DEWP  WIND   PAR  EVAP  RHUM
14259  16.1  20.5  13.8   0.0
14260  20.4  22.7  13.7   0.0
14261  21.6  23.4  15.4   3.9
14262  18.7  22.6  15.2  26.2
14263  17.3  21.6  14.3   2.1
14264  16.1  21.5  13.0   0.0
14265  20.1  21.7  13.0   0.0
14266  15.6  21.9  12.8   0.0
14267  12.0  20.4  13.1   0.3
14268  15.4  20.4  12.1   0.0
14269  16.1  20.1  11.6   0.0
14270  19.2  20.7  11.8   0.0
14271  17.0  20.0  11.6   0.2
14272  14.4  17.9  12.1   0.0
14273  15.3  17.6  10.9   0.0
14274  17.5  19.3  10.8   0.0
14275  16.5  18.7  12.3   0.0
14276  12.8  19.8  12.3   0.0
14277  18.5  20.9  12.5   0.0
14278  17.6  20.9  12.9   0.4
14279  18.8  20.9  12.8   0.1
14280  17.1  21.1  12.3   0.0
14281  20.9  20.4  11.7   0.0
14282  19.0  20.4  11.1   0.0
14283  18.6  20.2  10.2   0.0
14284  21.0  19.5   9.4   0.0
14285  20.8  20.1   9.9   0.4
14286  10.3  19.1   9.7  22.3
14287   2.7  14.9  10.7  32.3
14288  16.3  17.5   9.0   0.0
14289  16.0  18.3   7.5   0.0
14290  17.9  17.6   7.1   0.0
14291  15.1  16.8   7.2   0.9
14292  16.9  18.1   5.9   0.0
14293  15.8  17.5   7.8   0.0
14294  12.2  16.8   6.8   0.0
14295  17.7  17.9   8.6   0.0
14296  16.3  18.1   9.2   0.0
14297  16.8  17.2   8.1   0.1
14298  13.3  16.4   8.1   2.9
```

14299	10.6	16.5	5.5	0.0
14300	15.6	16.2	6.2	0.0
14301	12.2	15.4	6.6	0.0
14302	12.4	15.1	6.3	0.0
14303	14.3	15.9	6.0	0.0
14304	14.0	16.4	7.0	0.0
14305	10.3	17.2	8.5	0.9
14306	16.9	17.2	7.7	0.0
14307	16.3	16.9	7.3	0.0
14308	14.9	17.2	7.2	0.0
14309	14.2	16.0	5.8	0.0
14310	15.5	17.6	5.4	0.0
14311	16.7	17.6	7.5	0.0
14312	15.8	18.2	8.3	0.0
14313	17.2	18.1	8.2	0.0
14314	15.8	18.1	7.9	0.0
14315	16.0	18.6	8.3	0.0
14316	17.7	18.1	5.9	0.0
14317	16.2	17.9	5.9	0.0
14318	16.3	17.1	6.4	0.0
14319	13.8	17.1	6.8	0.1
14320	15.3	16.1	6.8	0.0
14321	14.9	16.0	5.0	0.0
14322	14.4	15.1	4.9	0.0
14323	14.1	15.7	5.5	0.0
14324	14.4	15.7	5.3	0.0
14325	15.2	15.6	5.9	0.0
14326	14.0	14.7	3.6	0.3
14327	16.2	14.5	3.0	0.0
14328	14.9	15.3	3.7	0.0
14329	14.1	14.6	4.8	0.0
14330	13.1	15.1	4.0	0.0
14331	10.6	14.2	4.3	0.0
14332	12.6	14.5	3.3	0.0
14333	14.5	15.9	3.5	0.0
14334	15.9	16.9	5.5	0.0
14335	15.1	17.3	6.0	0.0
14336	14.9	17.6	7.1	0.0
14337	15.2	18.0	6.7	0.0
14338	16.1	16.8	6.2	0.0
14339	15.7	16.2	6.3	0.0
14340	15.5	17.2	6.0	0.0
14341	15.4	15.8	5.6	0.0
14342	11.6	15.7	5.4	0.0
14343	15.8	15.7	4.2	0.0
14344	15.2	14.1	2.5	0.0
14345	15.8	14.5	2.5	0.0
14346	14.9	14.2	3.1	0.0
14347	2.5	14.2	3.4	18.4
14348	3.1	6.5	2.2	3.1

14349	8.0	10.4	1.9	0.1
14350	7.1	7.3	-0.2	0.0
14351	11.4	12.1	-2.0	0.0
14352	13.6	13.5	-1.3	0.0
14353	10.9	13.5	2.8	0.0
14354	13.5	14.0	2.9	0.0
14355	11.7	13.1	2.5	0.2
14356	11.8	12.7	2.6	0.2
14357	13.4	12.7	2.5	0.7
14358	13.6	13.0	2.2	0.0
14359	14.6	14.2	3.5	0.0
14360	13.7	12.7	1.9	0.0
14361	15.0	12.3	0.7	0.0
14362	14.4	12.6	1.0	0.0
14363	12.6	13.0	2.8	0.1
14364	14.7	12.5	1.8	0.0
14365	11.6	13.3	2.2	0.1
15001	4.4	13.2	3.8	16.1
15002	2.8	13.8	5.0	0.4
15003	2.4	13.7	4.7	3.6
15004	7.7	10.3	-0.9	0.0
15005	13.0	14.2	-1.8	0.0
15006	7.5	12.4	0.2	0.7
15007	8.5	10.1	-1.4	0.0
15008	12.2	10.5	-0.4	0.0
15009	12.9	12.9	-3.4	0.0
15010	13.8	14.0	-0.3	0.0
15011	11.1	14.6	2.5	0.5
15012	13.0	14.0	3.0	0.0
15013	14.4	13.3	2.7	0.0
15014	14.1	11.9	1.2	1.0
15015	14.8	10.1	1.1	0.0
15016	12.3	10.1	-0.9	0.0
15017	15.2	11.0	-1.9	0.0
15018	13.7	12.2	-0.3	0.0
15019	15.8	11.9	-0.6	0.0
15020	14.7	12.8	0.2	0.0
15021	16.2	13.0	2.2	0.0
15022	7.1	13.4	1.5	13.0
15023	11.5	12.1	1.5	0.2
15024	16.6	13.3	0.9	0.2
15025	14.3	13.2	1.7	4.6
15026	7.3	11.8	1.4	8.1
15027	14.2	11.4	0.9	0.0
15028	16.5	11.4	0.3	0.8
15029	14.2	10.8	-0.5	0.7
15030	15.4	10.2	-1.8	0.3
15031	16.7	12.1	-2.2	0.0
15032	13.6	11.9	-1.4	0.0
15033	13.8	11.9	0.8	0.0

15034	8.6	13.6	1.7	2.8
15035	16.3	14.0	0.9	0.0
15036	15.4	14.3	1.2	0.0
15037	16.3	14.2	1.1	0.0
15038	15.4	14.0	1.5	0.2
15039	6.0	13.3	0.5	3.3
15040	17.5	13.7	1.2	0.0
15041	16.7	14.3	0.6	0.0
15042	13.2	14.0	1.5	0.2
15043	9.9	13.1	0.6	6.2
15044	17.4	14.0	0.3	0.0
15045	13.1	14.3	1.0	1.2
15046	11.6	13.7	1.6	0.0
15047	16.8	15.5	3.5	0.7
15048	13.2	14.4	4.0	0.0
15049	12.6	13.4	2.6	5.2
15050	14.6	14.3	2.5	0.0
15051	18.3	16.6	1.7	0.9
15052	16.5	17.4	2.4	0.0
15053	19.3	19.4	2.7	0.0
15054	17.9	18.5	5.3	0.0
15055	15.8	19.4	5.9	0.6
15056	11.5	17.1	7.7	10.5
15057	6.9	11.1	5.5	2.9
15058	16.7	15.2	5.1	0.0
15059	9.1	16.2	3.0	14.1
15060	6.5	8.1	4.2	32.4
15061	5.4	6.4	1.9	9.1
15062	8.9	8.8	0.9	0.0
15063	14.0	7.6	-0.3	0.0
15064	16.7	12.5	-1.3	0.0
15065	18.3	14.1	-0.5	0.0
15066	16.4	15.1	-1.0	0.0
15067	16.4	15.5	2.1	0.0
15068	17.5	16.0	1.6	0.0
15069	20.4	16.8	-1.8	0.0
15070	19.6	18.3	1.9	0.0
15071	21.0	19.0	4.5	0.0
15072	16.5	18.8	4.9	0.1
15073	12.1	17.5	4.4	3.6
15074	4.0	14.2	5.6	10.4
15075	16.9	16.1	4.5	0.8
15076	19.8	16.6	3.6	0.0
15077	12.6	14.8	4.5	1.7
15078	18.3	16.9	2.6	0.0
15079	20.9	18.7	4.4	0.0
15080	17.0	18.9	5.5	0.0
15081	21.1	20.4	5.3	0.7
15082	17.2	20.1	6.1	3.5
15083	21.5	21.3	6.3	0.0

15084	17.7	20.8	8.1	8.8
15085	18.9	20.6	8.4	2.2
15086	11.9	19.4	10.1	8.2
15087	19.4	20.8	8.0	0.0
15088	14.5	18.8	9.4	5.1
15089	3.1	13.2	6.9	29.5
15090	20.2	17.7	5.5	0.0
15091	16.2	18.6	7.8	0.7
15092	16.1	19.7	7.9	0.0
15093	9.9	20.8	8.2	0.9
15094	6.3	19.5	6.2	9.7
15095	20.8	17.7	6.2	0.0
15096	19.8	18.8	5.1	0.0
15097	15.9	18.9	5.9	0.0
15098	19.6	19.0	4.9	0.0
15099	22.1	19.9	6.4	0.0
15100	20.4	21.2	7.5	0.0
15101	22.2	21.2	8.4	4.7
15102	8.1	21.0	7.7	16.7
15103	5.9	18.7	9.4	2.6
15104	11.2	17.5	9.9	7.0
15105	11.3	19.7	9.3	3.6
15106	18.4	21.0	9.6	0.4
15107	10.6	18.0	9.7	0.3
15108	18.9	20.5	7.7	0.0
15109	20.6	23.2	9.8	0.0
15110	19.8	24.5	10.4	0.0
15111	23.2	24.6	10.7	0.0
15112	17.4	22.9	10.0	0.4
15113	21.6	22.7	9.0	2.9
15114	13.6	22.4	8.0	21.6
15115	7.7	17.9	9.5	3.5
15116	12.5	15.6	9.4	0.0
15117	14.8	19.5	9.8	0.0
15118	7.9	18.8	10.8	14.3
15119	15.6	18.2	9.7	0.0
15120	19.9	21.3	9.2	0.5
15121	22.8	22.8	9.2	0.0
15122	20.6	22.2	9.6	0.0
15123	22.9	22.2	8.7	0.0
15124	23.8	23.8	8.0	0.0
15125	22.2	24.7	9.8	0.1
15126	17.7	25.1	11.4	1.3
15127	21.4	23.7	12.7	3.5
15128	19.3	25.6	11.8	6.2
15129	19.0	24.4	12.9	3.4
15130	15.0	26.2	12.0	9.3

Appendix 25. X file (TUIA1401.WHX) used for calibration and validation of CERES-Wheat using experiment

```
*EXP.DETAILS: TUIA1401WH ASSESSMENT OF WHEAT CULTIVARS, TILLAGE AND SOWING DATES
*GENERAL
@PEOPLE
Srijana Marasini
@ADDRESS
Kritipur, Kathmandu
@SITE
Kaski
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
    196    15     3   -99    20   SSP     6    10     3 anual
*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 ZT Local Nov 15            1  1  1  1  1  0  1  1  0  1  0  1  1
 2 1 1 0 ZT Local Nov 30            1  1  2  2  2  0  2  2  0  3  0  1  1
 3 1 1 0 ZT WK1204 Nov 15           2  1  1  1  1  0  1  1  0  1  0  4  1
 4 1 1 0 ZT WK1204 Nov 30           2  1  2  2  2  0  2  2  0  3  0  6  1
 5 1 1 0 ZT Annapurna4 Nov 15       3  1  1  1  1  0  1  1  0  1  0  1  1
 6 1 1 0 ZT Annapurna4 Nov 30       3  1  2  2  2  0  2  2  0  3  0  2  1
 7 1 1 0 ZT Gautam Nov 15           4  1  1  1  1  0  1  1  0  1  0  3  1
 8 1 1 0 ZT Gautam Nov 30           4  1  2  2  2  0  2  2  0  3  0  4  1
 9 1 1 0 CT Local Nov 15            1  1  1  1  1  0  1  3  0  2  0  3  1
10 1 1 0 CT Local Nov 30            1  1  2  2  2  0  2  4  0  4  0  1  1
11 1 1 0 CT WK1204 Nov 15           2  1  1  1  1  0  1  3  0  2  0  2  1
12 1 1 0 CT WK1204 Nov 30           2  1  2  2  2  0  2  4  0  4  0  5  1
13 1 1 0 CT Annapurna4 Nov 15       3  1  1  1  1  0  1  3  0  2  0  3  1
14 1 1 0 CT Annapurna4 Nov 30       3  1  2  2  2  0  2  4  0  4  0  5  1
15 1 1 0 CT Gautam Nov 15           4  1  1  1  1  0  1  3  0  2  0  1  1
16 1 1 0 CT Gautam Nov 30           4  1  2  2  2  0  2  4  0  4  0  5  1
*CULTIVARS
@C CR INGENO CNAME
 1 WH RA0014 Farmers local
```

```
 2 WH RA0015 WK-1204
 3 WH RA0016 Annapurna-4
 4 WH RA0017 Gautam
*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 TUIA1401 SRIJ       -99   -99 DR003    15  0.03   -99 SL     100  TUIA140001 SANDY LOAM
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1          28.28           83.85      1000               588    12  1.02   -99 FH101   -99
*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 14318 SA011 SA001 SA015  1st date
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    20   1.5  3.09   .27   6.2   -99  44.1 221.6   -99
 1    40   1.4  1.82   .15   6.5   -99    26 194.1   -99
 1    60   1.4  1.67   .15   6.4   -99  32.5 209.7   -99
 1    80   1.5  1.47   .12   6.8   -99  23.5 192.1   -99
 1   100   1.5  1.32   .11     7   -99  18.9   201   -99
@A SADAT  SMHB  SMPX  SMKE  SANAME
 2 14318 SA011 SA001 SA015  2st date
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 2    20   1.5  3.09   .27   6.2   -99  44.1 221.6   -99
 2    40   1.4  1.82   .15   6.5   -99    26 194.1   -99
 2    60   1.4  1.67   .15   6.4   -99  32.5 209.7   -99
 2    80   1.5  1.47   .12   6.8   -99  23.5 192.1   -99
 2   100   1.5  1.32   .11     7   -99  18.9   201   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    RI 14318   -99   -99     1     1   -99   -99   -99   -99   -99   -99 First date
@C  ICBL  SH2O  SNH4  SNO3
 1    20  .205    .1    .2
 1    40   .17     0    .1
 1    60  .092    .1    .1
 1    80  .065     0    .1
 1   100   .06     0    .1
```

```
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 2    RI 14333   -99   -99     1     1   -99   -99   -99   -99   -99   -99 Second date
@C  ICBL  SH2O  SNH4  SNO3
 2    20  .205    .1    .2
 2    40   .17     0    .1
 2    60  .092    .1    .1
 2    80  .065     0    .1
 2   100  .066     0    .1
*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
PLNAME
 1 14319 14328   290   280     S     R    20   -99     5   -99   -99   -99   -99   -99
Nov 15
 2 14334   -99   290   280     S     R    20   -99     5   -99   -99   -99   -99   -99
Nov 30
*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1     1    30    50   100 GS000 IR001    10 no irrigation
@I IDATE  IROP IRVAL
 1 14319   -99     0
*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 14319 FE005 AP007    10    24     0     0     0     0   -99 Nov 15, CS n CT
 1 14319 FE006 AP007    10    16    40     0     0     0   -99 Nov 15, CS n CT
 1 14319 FE016 AP007    10     0     0    20     0     0   -99 Nov 15, CS n CT
 1 14349 FE005 AP001     0    40     0     0     0     0   -99 Nov 15, CS n CT
 2 14334 FE005 AP007    10    24     0     0     0     0   -99 Nov 30, CS n CT
 2 14334 FE006 AP007    10    16    40     0     0     0   -99 Nov 30, CS n CT
 2 14334 FE016 AP007    10     0     0    20     0     0   -99 Nov 30, CS n CT
 2 14364 FE005 AP001     0    40     0     0     0     0   -99 Nov 30, CS n CT
*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 14319 RE003  5000   .75    .5     1     0    10 AP007 Vermicompost + FYM + Residue in ZT Nov 15
 1 14319 RE005  1500   1.5    .5   1.5   100    10 AP007 Vermicompost + FYM + Residue in ZT Nov 15
 1 14319 RE207 10000   .78   .14  1.72     0     0 AP001 Vermicompost + FYM + Residue in ZT Nov 15
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 2 14334 RE003  5000   .75    .5     1   100    10 AP007 Vermicompost + FYM + Residue in ZT Nov 30
 2 14334 RE005  1500   1.5    .5   1.5   100    10 AP007 Vermicompost + FYM + Residue in ZT Nov 30
 2 14334 RE207 10000   .78   .14  1.72     0     0 AP001 Vermicompost + FYM + Residue in ZT Nov 30
 3 14334 RE003  5000   .75    .5     1   100    15 AP002 Vermicompost + FYM in CT Nov 15
 3 14334 RE005  1500   1.5    .5   1.5   100    15 AP002 Vermicompost + FYM in CT Nov 15
 4 14334 RE003  5000   .75    .5     1   100    15 AP002 Vermicompost + FYM in CT Nov 30
 4 14334 RE005  1500   1.5    .5   1.5   100    15 AP002 Vermicompost + FYM in CT Nov 30
*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 14319   -99   -99   -99   -99   -99  -99
*TILLAGE AND ROTATIONS
@T TDATE TIMPL  TDEP TNAME
 1 14319 TI034    10 ZT Nov 15
 2 14318 TI042    25 CT Nov 15
 2 14319 TI021    15 CT Nov 15
 3 14334 TI034    10 ZT Nov 30
 4 14333 TI042    25 CT Nov 30
 4 14334 TI021    15 CT Nov 30
*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 14318 A   0 S   0 A   0 A   0 A 0.0 A   0 A   0 A   0
*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 15103 GS000     H     A   100   -99 local, ZT, CS, 15Nov
 2 15105 GS000     H     A   100   -99 Annapurna, ZT,15Nov
 3 15106 GS000     H     A   100   -99 Local, ZT, 30Nov
 4 15107 GS000     H     A   100   -99 Local,CT, 30Nov
 5 15109 GS000     H     A   100   -99 Gautam,ZT, Annapurna, CT,15Nov
 6 15117 GS000     H     A   100   -99 Gautam, CT, 15Nov
 7 15113 GS000     H     A   100   -99 WK 1204, ZT,CT, 15Nov
 8 15113 GS000     H     A   100   -99 Annapurna, ZT,30Nov
 9 15113 GS000     H     A   100   -99 Gautam, ZT, 30 Nov
10 15113 GS000     H     A   100   -99 Annapurna, Gautam, CT,30Nov
11 15113 GS000     H     A   100   -99 WK 1204, CT,30Nov
12 15113 GS000     H     A   100   -99 WK 1204, ZT,30Nov
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*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 14318  2150 Nov 14                    CSCER
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     Y     N     N     N     N     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     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     Y     N     Y     N     Y
@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          00001 00001    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 00001   100     0
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 2 GE              1     1     S 14333  2150 Nov 29                    CSCRP
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 2 OP              Y     Y     Y     N     N     N     N     Y     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 2 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 2 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 2 OU              N     Y     Y     1     Y     Y     Y     Y     Y     N     Y     N     Y
@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 2 PL          00001 00001    40   100    30    40    10
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@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 2 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 2 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 2 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 2 HA              0 00001   100     0
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BIOGRAPHICAL SKETCH

The author was born on 13th July 1990 at Dayanagar VDC ward number 3 Rupandehi, Nepal as 6th daughter of Mrs Kamala Marasini and Mr. Eak Dev Marasini. She completed her School Leaving Certificate (SLC) Examination from Public Higher Secondary School, Rupandehi with first division in 2005. She completed Intermediate in 2008 in First division from New Horizon College, Rupandehi. Then, she joined Institute of Agriculture and Animal Science (IAAS), Rampur Campus for B. Sc. Ag. Degree program in 2008 and completed her degree of Agriculture with major in Agricultural Economics in first division. Instantly, she joined the Masters Degree Program in Agriculture majoring in Agronomy in 2013. She got financial support for carrying out her research from CARITAS, Nepal. The author was awarded with Tribhuvan University Merit Scholarship during her Bachelor level and Master level. She received many prizes for her active participation in extracurricular activities during her study periods. She was happily married with Mr. Toyanath Joshi on April 22th 2014.

During her Bachelor and Master study, she attended several trainings and workshops/seminars organized at IAAS, Rampur and elsewhere in the country. The author has published various articles related to agriculture and animal science in international and national journals, proceedings and newspapers.

Author

SOME GLIMPSES OF RESEARCH


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