In-season crop yield forecasting using CCAFS Regional Agricultural Forecasting Toolbox (CRAFT) in Nepal

Working Paper No. 227

United Nations World Food Programme (WFP)

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Photos:

Abstract

The unpredictability of crop yields in climate vulnerable regions is damaging in many ways, negatively impacting food security as well as imports, exports, food prices, and people's livelihoods. The CCAFS Regional Agricultural Forecasting Toolbox (CRAFT) is an open source, flexible crop-forecasting platform that includes a crop simulation module, a weather and seasonal forecast simulation module, and a geographic information system module. The toolbox aims to provide information to ensure better management of agricultural risks associated with increased climate variability and extreme weather events. It uses historical databases of weather and crop yields and current weather to estimate yields of various crops. Advances in crop forecasting technology and crop modelling help with the estimation of in-season crop yields under a variable climate, which enables stakeholders such as policy makers, line agencies, cooperatives, extension workers, and farmers to better prepare the mitigation strategies to cope with risks. From November 2014 through December 2016, CRAFT was implemented in Nepal to forecast yields of wheat and paddy; forecast levels aligned closely with Ministry estimates. Currently, CRAFT is being tested for yield forecasting at the sub-national level in Nepal. The main objective of this paper is to present the status and performance of CRAFT for food security monitoring in Nepal. It presents the data inputs, the methodology and structure of the model, results and performance, limitations, and assumptions made in forecasting the yields of paddy and wheat for different seasons in Nepal.

Keywords

Yield Forecasting; CRAFT; Food Security Monitoring and Planning; Crop Outlook;

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Contents

Acronyms

AFU	Agriculture and Forestry University
CCAFS	Climate Change, Agriculture and Food Security
CERES	Crop Environment. Resource Synthesis
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CIMMYT	International Maize and Wheat Improvement Centre
CPT	Climate Prediction Tool
CRAFT	CCAFS' Regional Agricultural Forecasting Toolbox
CSM	Crop Simulation Models
DHM	Department of Hydrology and Meteorology
DoA	Department of Agriculture
DSSAT	Decision Support System for Agrotechnology Transfer
FAO	Food and Agriculture Organization
FEWS-NET	Famine Early Warning Systems Network
FoodSECuRE	Food Security Climate Resilience Facility
GIS	Geographic Information System
ICIMOD	International Centre for Integrated Mountain Development
IFAD	International Fund for Agricultural Development
IRI	The International Research Institute for Climate and Society
IRRI	International Rice Research Institute
ISRIC	International Soil Reference and Information Centre
IUSS	International Union of Soil Sciences

IWMI	International Water Management Institute
MoAD	Nepal Ministry of Agricultural Department
NARC	Nepal Agricultural Research Council
NDRI	Nepal Development Research Institute
NeKSAP	Nepal Food Security Monitoring System
NPC	National Planning Commission
SASCOF	South Asian Climate Outlook Forum
SOTER	Soil and Terrain Database
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
WFP	World Food Programme

Introduction

Climate-related risks, including crop failures and livestock deaths, can cause economic losses and undermine food security. This is likely to become more severe in the face of climate change (CCAFS, 2016). Failure to adapt to this change will inevitably bring about a sharp decline in food production, increase famines, and cause unprecedented setbacks in the fight against poverty in developing countries. These impacts also have social and economic consequences, resulting in changes in agricultural incomes, food markets, prices, trade patterns, and investment patterns. Reducing the high cost of risk and uncertainty associated with climatic variability is a crucial issue in any agricultural economy. Many governments need agricultural plans that aim to protect agricultural resources and facilitate food security under a changing climatic regime. Information on food availability is crucial to this type of agricultural planning and the information's availability, reliability, and usability can avert emergencies such as famines as well as support development and improve livelihoods. With recent advances in yield forecasting technology and crop modelling, it is now possible to estimate in-season crop yields well in advance to allow decision-makers and planners to better prepare for the risks emerging from a varying climate.

Crop yield forecasting refers to the prediction of the crop yield or production prior to the time of harvest. Amidst the ongoing climatic uncertainty, crop yield forecasts provide crucial information to many agricultural and food security policies, including food assistance, social safety net and emergency relief programs, agricultural insurance, and management of the agricultural inputs and credit supplies. Yield forecasting depends on data from various sources such as meteorological data (rainfall, temperature, humidity, bright sunshine hours, wind speed, wet spell, etc.), agro-meteorological data (phenology), soil data (water holding capacity), remote sensing data, and agricultural statistics. Models that simulate plant-weather-soil interactions in quantitative terms predict the crop yield over a given area, prior to the harvest, provided no extreme (statistically infrequent) conditions occur. These models are based on a "common sense" assumption that weather conditions are the main factor behind the inter-annual (short-term) variations for the de-trended crop yield series (Gommes et al., 2010).

Existing early warning tools for food security

Recent advances have seen new technologies—such as remote sensing and yield forecast based dynamic models—holding crucial relevance in the agricultural economies of South Asia, such as Nepal, Bangladesh, and India. Likewise, advances in the integration of seasonal climate forecasts and crop modelling offer a new avenue to address the in-season climate induced risks to agriculture that can have a profound impact on trade, farm-level management, food security early warning, and response in data sparse environments. There are several initiatives currently being implemented as early warning tools for food security. The World Food Programme (WFP)'s Food Security Climate Resilience (FoodSECuRE) Facility initiative links climate and hazard forecasting, providing governments the means to quickly avail funding to scale-up food and nutrition responses before climate disasters occur (WFP, 2016). This system is currently being implemented in the Philippines, Guatemala, Niger, Sudan, and Zimbabwe. Similarly, the Livelihoods, Early Assessment and Protection project (LEAP) system—developed by the Government of Ethiopia in collaboration with WFP in 2008—uses agro-meteorological monitoring data to estimate future crop yields and rangeland production, allowing funding to be triggered in a timely manner in case of shock to assist the additional people at risk of food insecurity. Another, the U.S. Agency for International Development (USAID)'s Famine Early Warning Systems Network (FEWS-NET) has been providing early warning and evidence-based analysis on food insecurity to help decision-makers plan for humanitarian crises in 35 countries around the world (FEWS-NET, 2016). South Asian Climate Outlook Forum (SASCOF) also provides seasonal outlooks of climate over the South Asia Region.

Current status of yield estimation in Nepal

Reliable, scientific, timely, and precise crop yield forecasts are important in Nepal. The conventional yield estimation technique in Nepal is based on reports from District Agriculture Development Offices, field visits, and crop cuts. It is carried out by the Agri-business Promotion and Statistical Division under the Ministry of Agricultural Development, in co-ordination with the Market Research and Statistics Management Program under the Department of Agriculture. Conventional yield estimation is time-consuming and prone to errors. The information is generally available only after harvest, too late to trigger timely action. A robust regional yield forecast model, coupled with the seasonal weather forecasts, information about soils and management, and remote sensing data (vegetation, soil moisture, etc.) can help address the need for early, reliable crop yield assessment.

CRAFT: An innovating new tool for crop product forecasting

CCAFS has developed a flexible, adaptable, accessible software platform to support within-season forecasting of crop production; and secondarily, risk analysis and climate change impact studies. The CCAFS Regional Agricultural Forecasting Toolbox (CRAFT), customized for South Asia, provides an information platform for within-season forecasting of crop production to support governments' efforts to build resilience. The purpose of adopting CRAFT is to anticipate the impacts of climate variations on crop production in support of agricultural management and food security decisions. CRAFT provides an information platform to support resilience-building interventions through within-season forecasting of crop production, risk analysis, and climate change impacts. It provides a robust platform which utilizes seasonal climatic forecasts and crop growth simulation model to forecast crop yield estimates. Thus, CRAFT stands out as a robust tool in comparison to other existing yield estimation practices around the world. The forecasts from CRAFT can provide a highly relevant and flexible platform that can be tailored to meet the needs of farmers, researchers, and food security decision-makers. The Toolbox can help policy makers by providing early probabilistic estimates of the volume of crop production in specific areas at different times of the year.

CRAFT is being used in Nepal, where process-based crop models were used with geospatial databases for arriving at crop forecasts. The tool is also being piloted in Bangladesh, Sri Lanka, and India.

Basis for CRAFT

Limited comparison of alternative methods suggested that using a statistical model to condition the output (e.g. simulated yield) of a crop simulation model on seasonal forecasts is simpler to implement and less prone to systematic error than the various methods that have been tested to condition crop model weather data inputs on seasonal forecasts (Hansen and Indeje 2004; Hansen et. al, 2006). The approach used in CRAFT builds on an earlier study that using principal components linear regression to link CGM-based seasonal precipitation forecast fields with model-based estimates of wheat yields in the state of Queensland, Australia (Hansen et al., 2004). Using a simple water balance-based wheat yield model, run on a set of polygons with historic station weather records and dominant soil data, the study predicted yields as a linear function of the first principal component of general circulation model (GCM) seasonal rainfall fields, over a spatial domain extending north and east from Queensland. Prediction skill was tested with hindcast analysis, employing leave-one-out cross-validation to ensure that observations from the year being predicted did not influence the statistical model. Predictions were updated four times, at monthly intervals, starting before the earliest planting in the state. In each case, the model was run with observed weather from the year being predicted through the forecast date, and then with all other years of available weather data from the forecast date until harvest. The forecast distribution was based on the cross-validated hindcast residual distribution (see Hansen et al., 2006).

CRAFT uses the same general approach, but is designed to work with gridded input data. The IRI's Climate Predictability Tool (CPT; Mason and Tippett 2016) runs in batch mode in the background, providing the multivariate statistical modelling used to downscale appropriate seasonal predictors (e.g. GCM output fields and observed or forecast sea surface temperature fields) into yields simulated with historic gridded weather data. CPT has more than 15 years of development and has been used by many national meteorological services and regional climate outlook forums to produce, downscale, and evaluate seasonal forecasts. It supports canonical correlation (treating predictor and predictand as spatial fields), principal component regression (treating predictor as a spatial field and predictand as independent points), and cross-validation to avoid over-fitting and the risk of artificial skill.

Once yields are predicted or simulated for grid cells containing the target crop, aggregate production is estimated by summing the product of grid cell yields and the fraction of the grid cell devoted to the crop, while ensuring that the grid cell forecast probability distributions are aggregated properly.

CRAFT Architecture

CRAFT includes the client application with a user-friendly interface and database implementation (Vakhtang et al., 2015). CRAFT integrates two different external engines: a crop simulation model for spatial crop simulations and another for seasonal climate forecasts using the CPT.

The crop simulation engine, the Decision Support System for Agrotechnology Transfer (DSSAT; Jones et al., 2003), consists of crop simulation models for cereals and many other crops, and the tools to facilitate effective use of the models. DSSAT simulates the crop-soil-weather interaction and gives crop yield as output. Likewise, the CPT is a tool that produces seasonal climate forecasts using model output statistic (MOS) corrections to climate predictions from GCM, or for producing forecasts using fields of sea-surface temperatures or similar predictors (IRI, 2017).

The workflow in CRAFT starts with management, soil and weather inputs in gridded forms which are utilized by the crop simulation module under DSSAT to produce yields. The CPT module then produces seasonal climate forecasts and integrates with the DSSAT simulated yields to provide seasonally forecasted yields for each of the grids. These gridded yields are aggregated to the domain of interest by a GIS module inside CRAFT. The yields are then compared and calibrated externally against observed data to obtain the final yield forecasts.

Figure 1 presents the flow diagram of CRAFT with four major steps (e.g. crop model, statistical model, aggregation and calibration).

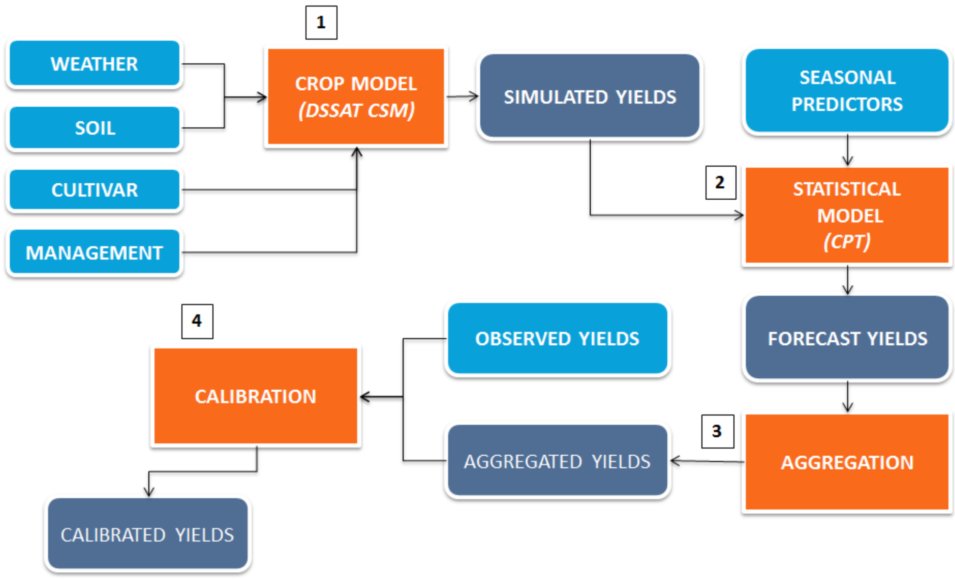

Figure 1: CRAFT process flow diagram (Hansen, 2013)

The CRAFT architecture uses gridded data schemes for spatial variability with predefined reference grids of 5 arc minute resolutions. Spatial inputs of weather, soil, cultivar and crop management inputs representing the reference schematized grids are initialized and incorporated into the crop simulation model (DSSAT CSM). The crop simulation engine then simulates the crop growth and yields for each individual grid cell based on the predefined inputs. If seasonal predictors are available, the yields are then adjusted using statistical downscaling as described in the previous section. Through spatial aggregation and probabilistic analysis of the forecast uncertainty for both short-term and long-term periods, predicted yield can be determined for a region at different spatial resolutions. (Vakhtang et al., 2015). CRAFT allows hindcast analysis, de-trending, and post-simulation calibration of model predictions from historic agricultural statistics. It includes further options for risk analysis and climate change impact studies on crops. Analyses of the simulation results can be conducted through comparing different scenarios, reviewing the output statistics and visualization with thematic maps.

Methods

Static spatial inputs

The inputs are added to CRAFT in gridded formats. The pre-processing of the data to assign to each grid was done in Arc-GIS interface. Basically, two types of data inputs are used in CRAFT: spatial and spatio-temporal inputs. Brief explanation of the data is given below:

The spatial inputs include soil data, cultivar type, crop management inputs and irrigation mask. These data are more or less constant for a given period of time. Specific details of the inputs used for different seasons are presented in Table 1.

The Soil and Terrain Database (SOTER) for Nepal was used as the soil source and the respective properties, such as texture, depth, soil moisture content, bulk density, infiltration capacity, and organic matter content (Dijkshoorn and Huting, 2009) were added to the CRAFT database and used for modelling. The SOTER database, at a scale of 1:1 million, is supported by the Food and Agriculture Organization of the United Nations (FAO), ISRIC-World Soil Information and the United Nations Environmental Programme (UNEP) under the umbrella of the International Union of Soil Science (IUSS) to create a global soil and terrain cover. Fig. 2 shows the SOTER soil map of Nepal.

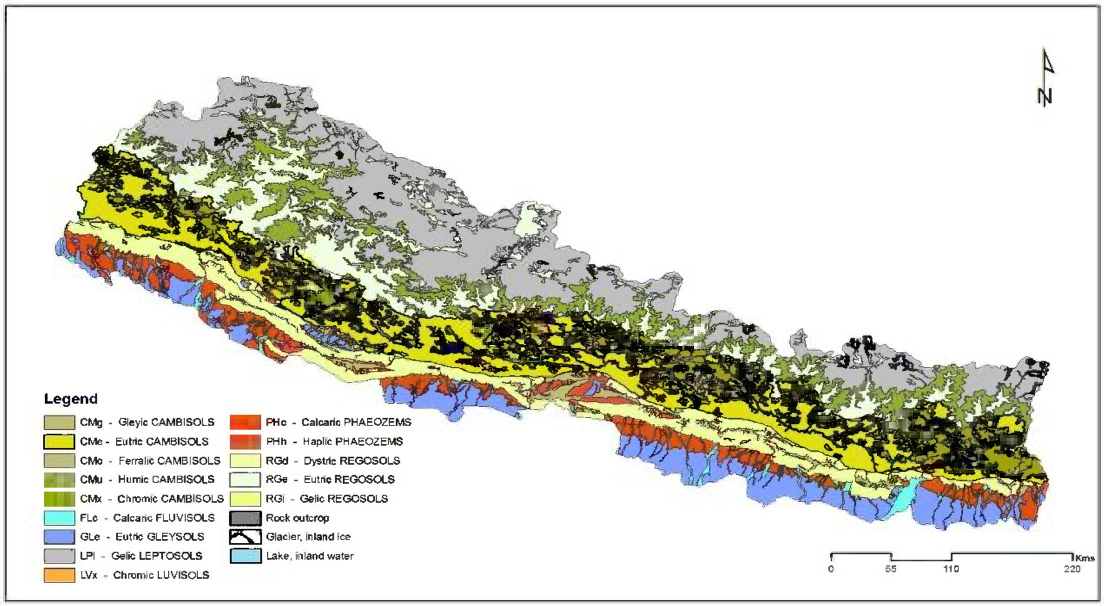

Figure 2: SOTER Soil map of Nepal

Crop management

Crop management practices including dates of sowing/planting, irrigation, and fertilizer applications were defined for the crops based on ecological belts: mountains, hills, and plains (Terai). These assumptions were based on the studies conducted by Gautam et al. (2011), Hobbs et al. (1996), Adhikari et al. (1999), and Amgain and Timsina (2005). Details are given in Table 1.

Cultivar data

Data on crop variety and more importantly the cultivar coefficients are the most important parameters governing the reliability of any crop model. Due to the absence of a clear crop varietal distribution in a spatial scale in Nepal, the crop varieties were chosen as the popular cultivars for each ecological zone. RR-21 for the hills and NL-297 varieties for the plains (Terai) were selected as the popular wheat cultivars. For paddy, Jumli Marshy was selected as the popular cultivar for the mountains, Khumal–4 for the hills, and Mansuli for the plains (Terai). Regarding the cultivar coefficients, calibrated genotypes obtained from the Nepal Agricultural Research Council (NARC) were used as the cultivar coefficients.

Irrigated area mask

The spatial distribution of irrigated areas across the grids constitutes this input data. Ministry of Agricultural Development's (MoAD) statistics on the district level irrigated area were used for irrigation mask. The ratio of irrigated area to the total area for each district was calculated and this proportion was uniformly distributed to each grid within a district to get irrigated area mask for Nepal.

Spatio-temporal Inputs

The spatio-temporal inputs include more time variant inputs such as weather data and crop acreage data. Specific details of these inputs used for different seasons are also presented in Table 1.

Weather data

Weather is the major driver of the CRAFT model, and the reliability of climatic parameters determine the reliability of model outcomes (i.e. the yield and production forecasts). Department of Hydrology and Meteorology (DHM) ground station data for precipitation and temperature for a time period of 1981 to 2009 on a daily scale were used in the model run. The precipitation data was taken from 163 stations and temperature from 45 stations across Nepal. The stations were selected based on the availability of the weather parameters. These data were interpolated in 5’ x 5’ schema grids using the nearest neighbourhood method.

Near-real time data is a prerequisite to get reliable yield forecasts. Since the availability of near-real time data is lacking in Nepal, the satellite based weather products were opted for supplementing the existing historic climate data till the date of simulation. Beyond 2009, the weather data was supplemented using other satellite precipitation and temperature estimates. The supplementary weather data used was 0.1° RFE v 2.0 data.

Crop mask

This data includes the spatial distribution of the areas under cultivation. Crop masks are periodically created for Nepal using the MoAD’s district-level statistics on a crop grown area for different stages within a crop season. The ratio of crop grown area to the total area for each district was calculated and this proportion was uniformly distributed to each grid within a district to get a distributed crop mask for Nepal. Due to the absence of reliable high resolution remote sensing products, the statistical area data from MoAD were incorporated. ICIMOD’s MODIS based cropped area distribution maps were tried but the data was later rejected due to the poor spatial resolution of MODIS.

Forecast timings

For the forecast, the crop masks were used twice in a season. The data was availed by the MoAD, once the information from all the districts were collected at the central level. Based on these data, the forecasts were made once during the maturity period and the other towards the end of the season (prior to or immediately after the harvest based on the availability of crop mask).

Table 1: Spatial Inputs used for CRAFT based on crop season

Inputs		Weather	Crop Mask	Irrigation Mask	Varieties	Planting	Irrigation application	N- Fertilizer application
2015-2016 Wheat	*1st estimate*	*DHM till 2009 and RFe 2.0 for till 2016*	15. Feb 2016	Irrigated area statistics from 2014-2015	Hills: RR-21 Terai: NL-297	*Hills: 11.Dec 2015 Terai: 2.Dec 2015	*Hills: 450mm Terai: 600mm	Hills: 60kg/ha Terai: 60kg/ha
	2nd estimate		20. Apr 2016					
2015 Paddy	*1st estimate*	*DHM till 2009 and RFe 2.0 for till 2015*	05. Aug 2015	Irrigated area statistics from 2014-2015	Mountains: Jumly Marshy Hills: Khumal -4 Terai: Mansuli	Mountains: 7.Jul 2015 Hills: 10.Jul Terai: 11.Jul	Hills: 1000mm Terai: 1200mm	Hills: 80kg/ha Terai: 80kg/ha
	2nd estimate		29. Aug 2015					
2014-2015 Wheat	*1st estimate*	*DHM till 2009 and RFe 2.0 for till 2015*	10. Feb 2015	Irrigated area statistics from 2013-2014	Hills: RR-21 Terai: NL-297	Hills: December 1 Terai: November 22	Hills: 600 mm Terai: 800mm	Hills: 60kg/ha Terai: 60kg/ha
	2nd estimate		10. Mar 2015					

* Adjusted for unfavourable conditions, as described in the next section.

Assumptions and limitations

This section discusses about the implementation of the CRAFT model in Nepal in relation with the limitation of CRAFT, assumptions considered and the implication of these assumptions.

Schema grid size

The schema grid size within CRAFT is 5' × 5' (roughly 81km^2), which is a fairly big size for Nepal, with a high level of heterogeneity in climatic as well as agricultural conditions within the grid area. However, since CRAFT offers no option for changing the schema grid size, the existing grids were used as reference grids and inputs were customized to fit them. Due to this, CRAFT results are limited to national scale or to a regional scale to the most despite a high demand from the MoAD to implement CRAFT at local scales.

Gridded weather data

The Department of Hydrology and Meteorology (DHM) of Nepal does not have the weather data available in a gridded format for Nepal. This was one of the limitations for the model. In absence of gridded weather data to be fed into the model, ground station data were interpolated to grids based on nearest neighbourhood method. The assumption was complemented by the provision of a greater frequency of weather stations. It was also assumed that the interpolation method holds well for hills and the plains (Terai) region with a higher frequency of stations. These regions are the predominantly cropped areas whereas the mountain region—where the interpolation could be wrong—has nominal cultivation.

Near real-time weather data

Due to the lack of DHM's near real-time data required for the seasonal weather forecast in CRAFT, ground-based observations were not used in the model. Instead, the weather data was supplemented using RFE 2.0 estimates, which was selected due to sufficient length of record. In the absence of ground based measurement, the CRAFT results need to be considered with caution.

Climate Predictability Tool within CRAFT

The CPT tool within CRAFT v 2.0 could not be run due to technical issues. As a result, workaround was devised to infill the crop season so as to run the crop model over the season for predicting seasonal yields. As an alternative, the near-real time weather information available from the DHM[1] of 20 synoptic and aeronautical stations across Nepal were used to interpolate the weather conditions for each grid and supplement the weather information until the day of forecast. The weather information for the remainder of the year (the forecast year) was infilled using the data from previous year. These years were assumed as those years with similar annual precipitation from the same station or a nearby station within the nearest elevation. With the complete series infilled for the year, CRAFT was then run to obtain the yield estimates. As the season progressed, the results were assumed to be less uncertain.

Crop specific data unavailability

Lack of available information on crop varietal distribution and management datasets at the grid level was another major limitation to the model. In the absence of information on crop varieties, irrigation, fertilizer input, and cultivated and irrigated area, the model run has been limited to the national level aggregation only. Thus generic management practices quoted in different studies at the ecological zones (mountains, hills, and plains) were selected for the model. Most popular cultivar varieties obtained through field consultations and reports were used in the model based on the ecological zones. This varietal information was further limited by the availability of the field verified cultivar coefficients. Cultivar coefficients available from the NARC were used in the model.

Adjustments for unfavourable conditions

Due to unfavourable conditions in the aftermath of the devastating earthquakes in April-May 2015 and the cross-border trade disruption with India during monsoon season of 2015, the agriculture sector was significantly affected. A resulting fuel crisis reduced irrigation application during sowing and crop growth. The condition was further worsened by a weak monsoon (2015) that reduced soil moisture during sowing. To simulate these unfavourable

[1] The near-real time data were obtained after an MoU with DHM following a series of discussions between WFP and DHM.

conditions, it was assumed in the model that the irrigated areas were reduced by 25% and the sowing was delayed by 10 days. The sowing dates for the hills ecological belt were assumed to be December 11 and for the plains (Terai) to be December 2. The summer and winter, crop assessment missions also affirmed the late sowing of wheat due to insufficient soil moisture.

Dissemination of results

The results from CRAFT are disseminated on a periodic basis in forms of advance estimates, as well as a dedicated section in Nepal Food Security Monitoring System (NeKSAP) publications such as Crop Situation Updates, Food Security Bulletins and CRAFT Reports. Advance estimates obtained through CRAFT were also shared with MoAD and other related stakeholders regularly. The results from CRAFT were also picked up by national media outlets and featured in news articles.

Results and Discussion

CRAFT has performed well with good results at the national scale. With this success, the stakeholders are now demanding its applications at the sub-national level. This, however, suggests the need for further improvements in data inputs as well as the model.

Validation by hindcast analysis

Hindcast analysis using CERES-Wheat Model

Once the aforementioned spatial-temporal inputs were prepared and entered into the model, CRAFT was used first to compute wheat yields by hindcasting to establish the validity of the model across the historical time series, prior to forecast. The model was run to hindcast the production for each year from 1983 to 2013 and the simulated values were compared against the reported production from MoAD for the corresponding years. Hindcasting for each past season was done by allowing the model to run through the corresponding season from the date of simulation for the same year. Due to a lack of adequate information on crop management and varieties over the time series, it was assumed that the varieties and management practices remained constant throughout the years. This has been the key limitation of the hindcast study.

Based on the comparison of the hindcast results and the observed production data, the model run showed a strong correlation between the observed and the simulated yields in Nepal. The scatter plot between the observed and simulated production and coefficient of determination (R2) of 0.88 also indicate that the model performance is satisfactory (Fig. 3). The year-wise hindcasted production values are given in Fig. 4 and Appendix.

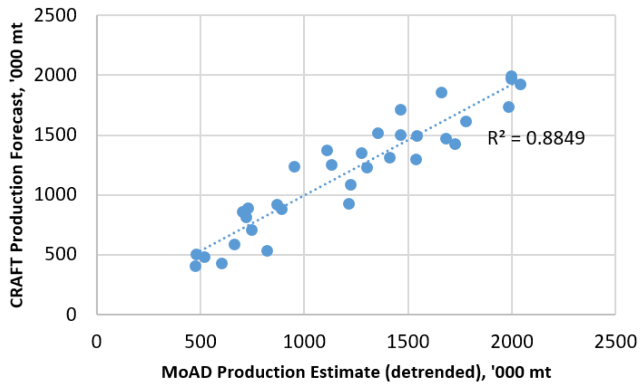

Figure 3: Comparison between CRAFT and MoAD production estimates for wheat (1983-2013)

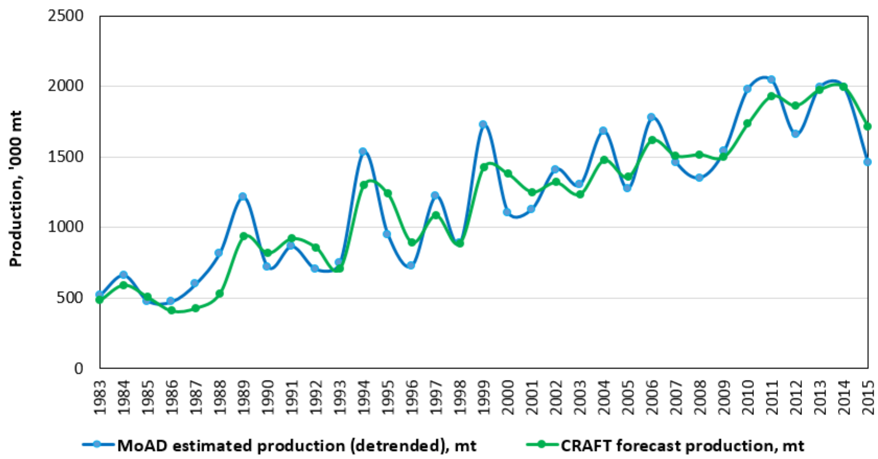

Figure 4: CRAFT forecasted and MoAD production estimates for wheat (1983-2015) (thousands of tonnes)

Hindcast analysis using CERES-Rice Model

Similar to the wheat model, CRAFT was used to hindcast the rice production levels from 1991 to 2014. The methodology was same. The simulated values were compared against reported rice production values for each year. With a corresponding coefficient of determination 0.6657, the results suggest that the model still has some room for further improvement (Fig. 5). The year-wise hindcast production values are given in the Appendix. Since paddy is highly sensitive to the climatic inputs, the model results require further calibration (especially with climate parameters) to establish a very sound validity for model application for paddy. This would be a focus of future research where high resolution climatic datasets (e.g. satellite precipitation) will be used to improve the forecast skills for paddy.

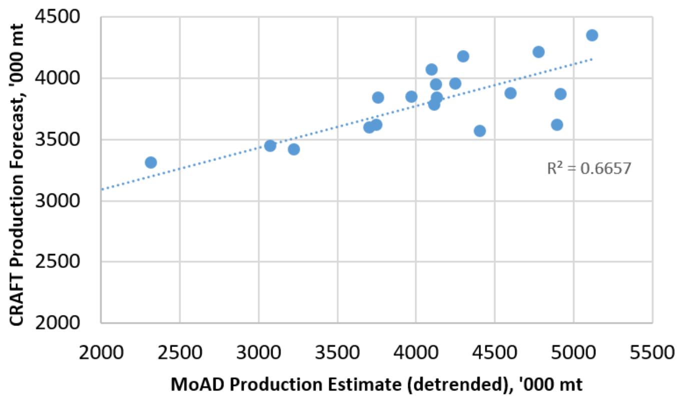

Figure 5: Comparison between CRAFT and MoAD production estimates for rice (1991-2014) (thousands of tonnes)

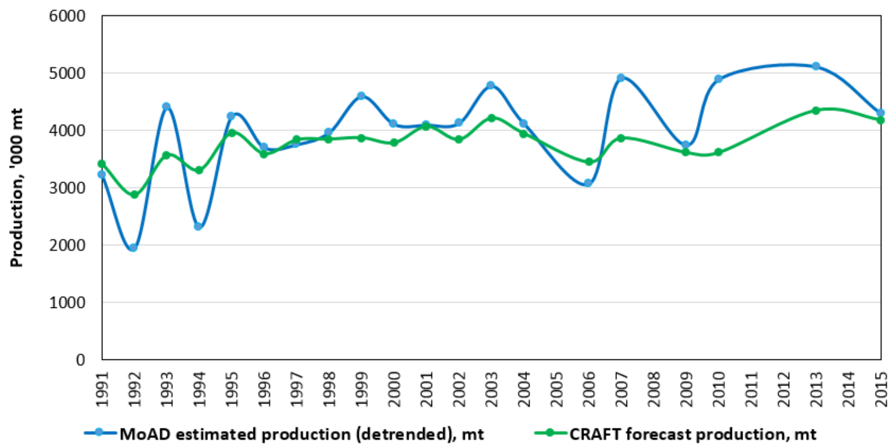

Figure 6: CRAFT forecasted and MoAD production estimates for wheat (1991-2015) (thousands of tonnes)

Results by crop season

After the validation of CERES-WHEAT and CERES-RICE model in CRAFT, the production estimates were simulated for each season and disseminated as in-season production outlook at various stages of crop growth. The results are summarized in Fig. 7 and Table 2 below.

Wheat production outlook 2015-2016

Two production outlooks for wheat for the season were put forward using the crop acreage at two different stages within the season.

For the preliminary wheat outlook 2016 season (with the wheat mask as of February 15, 2016), the model prediction run was based on the wheat cropped area estimate until February 15 and the result is presented in Fig. 2. As shown in the figure, wheat areas were reported at 723,754 ha—a decrease of 5% compared to the last year. The model forecasted a production of 1,570,746 tonnes, which is a 20.5% reduction compared to 2014-2015 and a 16% reduction compared to the five-year average production (normal level).

For the final wheat outlook 2016 season (with the wheat mask as of April 20, 2016), the preliminary result was updated with updated cropped area data obtained from MoAD signalling the end of wheat plantation. The model forecast is presented in Fig. 3. As shown in the figure, based on the updated area estimate of April 20, the model forecasted a production of 1,718,120 tonnes from 756,547 ha (0.8% reduction from last year). The outlook was a 13% reduction compared to the last year and 8% reduction compared to the normal level.

Paddy production outlook 2015

Similarly, two production outlooks for paddy were produced in the post-earthquake scenario, using the crop acreage at two different stages within the season.

For the preliminary paddy outlook 2015 season (with the paddy mask as of 5 August 2015), the preliminary model run was based on the paddy crop area estimate provided by MoAD (as of 5 August 2015), which suggested an area of 1,046,928 ha— 26% less compared to that of 2014. The model forecasted a production of 3,194,774 tonnes—a reduction of 33.4% and 33% compared to 2014-2015 and normal production levels.

For the final paddy outlook 2015 season (with the paddy mask as of 29 August 2015), the preliminary result was updated with the updated crop area obtained from MoAD, which signalled the end of paddy plantation. The updated forecast is presented in Fig. 4. As shown in the figure, based on the updated area estimate of 29 August 2015, a production of 4,181,298 tonnes was forecasted from a planted area of 1,370,212 ha (a 4.5% reduction from last year). At 4,181,298 tonnes, the forecast was a 12.3% reduction compared to 2014, in the post-earthquake scenario in Nepal. Likewise, in comparison to the normal level, the forecast was a 12.4% reduction.

Wheat production outlook 2014-2015

CRAFT was used to forecast the national level wheat production for 2014-2015 for the first time. Two outlooks were provided at different stages of cropping season.

For the preliminary wheat outlook 2016 season, the forecast was for production of 2,230,660 tonnes, an increase of 18.5% compared to 2013-2014 and an increase 27.3% compared to the five-year average or normal level.

For the final wheat outlook 2014-2015 season (with climate data to 10 March 2015), the model was rerun with updated climate data of 10 March 2015 and the model calibration was further improved to get the updated outlook for the winter season. The updated results showed final wheat production outlook for 2014-2015 at 1,994,598 mt, with an average prediction uncertainty. The forecast indicated an increase of 5.9% compared to 2013-2014 and an increase 13.9% compared to the five-year average.

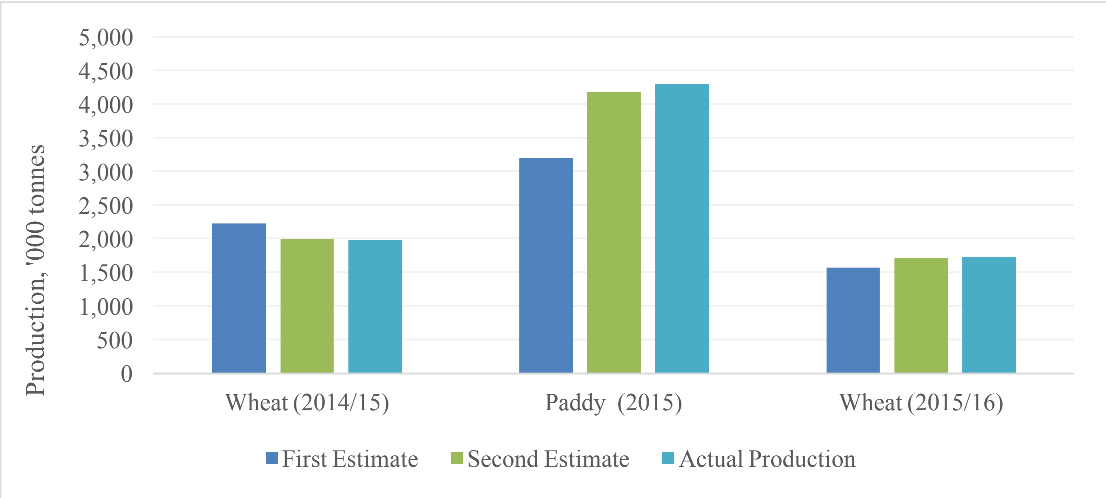

Figure 7: Yield forecast results using CRAFT for 2014-2015 and 2015-2016 seasons

Table 2: Summary of CRAFT results

Seasons	Estimates	Date of Forecast	Cropped Area (ha)	Forecasted Production (tonne)	Actual Production (tonne)	Deviation from actual production (%)	Change from last year's production (%)	Change from normal (%)
Wheat (2015-2016)	2nd Estimate	20. Apr 2016	756,547	1,718,120	1,736,849	1.08	13	8
	1st Estimate	20. Feb 2016	723,754	1,570,746	1,736,849	10.04	20.5	16
Paddy (2015)	2nd Estimate	29. Aug 2015	1,370,212	4,181,298	4,299,078	-2.64	12.3	12.4
	1st Estimate	05. Aug 2015	1,046,928	3,194,774	4,299,078	-25.69	-33.4	-33
Wheat (2014-2015)	2nd Estimate	10 Mar 2015	762,367	1,994,598	1,975,607	0.97	5.9	13.9
	1st Estimate	10. Feb 2015	762,367	2,230,660	1,975,607	12.9	18.5	27.3

Implications of assumptions and key limitations

The results from CRAFT suggest a good applicability at the national level as the final outlooks have adequately matched the MoAD's estimate that is disseminated almost a month after the harvest. These advance estimates have the potential to inform food security related decisions in Nepal. Despite the data limitations, the model has shown good prediction capability for crop yields.

As discussed above, the major limitation was the climate data, which has been addressed by using the satellite-based products. However, for a better representation of Nepal's climatic scenario, DHM's station data should be used. Lack of capacity and technical issues surrounding the CPT was another major obstacle in assessing the in-season climate required for the production estimate. Workarounds were devised for further application of CRAFT, it included alternatives to the seasonal forecast module, interpolated gridded climate and soil data. However, there is room for improvement regarding the current limitations on climate data. With the newer versions of CRAFT, a working CPT module would be highly relevant in putting forward 'actual' seasonal forecasts in the estimation process.

Likewise, the absence of real-time satellite based crop-masks have restricted the application of CRAFT to the MoAD's district-level area estimates, which has limited the CRAFT capabilities to the district level as the smallest unit of prediction instead of grids. The scenario is similar for irrigation masks.

Crop varietal information has been gradually improved as more and more stakeholders are sharing their information regarding varietal mapping in Nepal. The soil database is also being continually explored to ensure better inputs to the model. Frequent transfer of the CRAFT trained focal points in the MoAD and NARC has also been a hindering factor. Regarding the results, the model has been showing good prediction for wheat compared to rice.

The first phase (November 2014 – December 2016) of CRAFT has seen challenges ranging from technical data and input oriented issues to a more managerial issue in uptake from the counterparts as well as capacity development. Amidst these challenges, CRAFT has increasingly gained its recognition as a potential yield forecasting and decision support tool in Nepal.

The progress made towards the aforementioned specific challenges during the first phase of CRAFT implementation are discussed below:

Input Data and downscaling

The quality of model output depends upon the quality of data available. Hence, the model output can still be improved with more precise inputs especially on weather, crop mask, cultivars and crop management. On the other hand, there is an increasing demand for downscaling the model outputs to sub-national (regional and district) levels. However, availability of disaggregated inputs/data at those levels remains a challenge. The following sections briefly highlights the data issue vis-à-vis refining and downscaling the model outputs.

Real-time climate data

In the absence of a mechanism for regular data provision from DHM to NeKSAP, the real-time climate data was not available for the model run. The real-time climate data is a crucial input to CRAFT for reliable seasonal production forecasts. However, in the early stages, due to the lack of such data, satellite-based climate estimates were used in conjunction with the DHM data. A mechanism was thus needed to facilitate provision of DHM's weather data on a regular basis to update the model and get updated forecasts.

After a series of discussions, DHM has started providing real-time data from 20 automated weather stations across Nepal on a regular basis from May 2016. Also, a climate database required for CRAFT is currently being developed by WFP and CCAFS—which will significantly improve the model predictions at a sub-national scale.

Inclusion of different crop varieties at district level

Due to the lack of crop cultivar coefficients, one of the most important inputs to the model—only one variety per crop per ecological belt was used in the simulation. A lot of varietal research is undertaken and cultivar coefficients available at Nepal Agricultural Research Council (NARC). This particular information must be tapped for improving the forecast skills. As of now, the exercise relied on limited varieties, some of which are quite old.

At this stage, NARC, Institute of Agriculture and Animal Science (IAAS), and Agriculture and Forestry University (AFU) have agreed to provide the coefficients of any new cultivars that are released. Furthermore, the project recently received the rice varietal mapping undertaken by the Crop Development Directorate of Nepal, which is expected to fine tune the rice varieties at the district level to be incorporated into the model.

Crop and irrigated areas, and management data

Another major data gap was the availability of reliable crop acreage data. So far, the MoAD's estimated crop area within the season is being considered as a reference in the model as it is the case with the irrigation coverage. On the other hand, the variety specific crop management data (irrigation, fertilizer application, planting, etc.) is not available at the desired sub-national scale. This is also one of the major factors limiting the model capability at the district level.

With recent advances in remote sensing based crop monitoring approaches, the International Centre for Integrated Mountain Development (ICIMOD) has provided remote sensing products to estimate the crop area for the plains (Terai) region. With the introduction of the SENTINEL-II data, ICIMOD is planning to expand the coverage across Nepal, given the high spatial resolution of SENTINEL-II. A recent independent review of the current crop monitoring and crop estimation practices in Nepal noted the potential of crop yield forecasting and remote sensing as valuable contributions to update existing practices.

Regarding crop management data, efforts are now being made to obtain the data at the district scale via incorporation of revised questionnaires in the seasonal crop assessment mission.

Conclusion and Recommendations

NeKSAP piloted CRAFT to provide advance estimates of cereal crop production (paddy and maize) to the government and other stakeholders to support food security planning in the country. The encouraging results obtained for the wheat forecast in 2014-2015 season resulted in establishing the credibility of the CRAFT methodology with the Ministry of Agriculture and Development, Nepal. The deliberations with them then lead to implementation of CRAFT for estimating production for 2015 paddy and subsequent 2015-2016 wheat season.

While MoAD's official estimate of 2015-2016 winter wheat production were released on (22 June, 2016), CRAFT estimates were available well in advance, with the first and second estimates released on 20 February and 20 April respectively. The second advance estimate forecasted wheat production at 1,718,120 tonnes—a 13% reduction compared to the previous year and 8% reduction compared to the normal level. The CRAFT production estimate differed by just 1% from MoAD's official release estimated as 1,736,849 tonnes.

CRAFT generated estimates for 2015 paddy and 2014-2015 wheat aligned closely with MoAD's official production estimates. The second advance estimate of 2015 paddy that was released on 29 August 2015 estimated a production of 4,181,298 tonnes, which was 2.64% less than MoAD's official estimate of 4,299,078 tonnes. The second estimate of 2014-2015 winter wheat production using CRAFT was even closer to MoAD's official estimate with the prediction error of less than 1%: the CRAFT estimate was 1,994,598 tonnes compared to MoAD's estimate of 1,975,607 tonnes.

The advance estimates were shared with MoAD and other stakeholders in different forums and the results were disseminated through NeKSAP publications, NeKSAP website, and NeKSAP Google Group. Some of the advance estimates were also covered in the national media. Downscaling these forecasts to sub-national levels is required, which would require improvement in the quality of inputs and wider cooperation for data sharing (e.g. the climate data, the cultivar data, etc.). Further, developing the capacity of the stakeholders in running the models and to generate production estimates well in advance is equally important.

Although model results at the national level were considered satisfactory for the pilot phase for CRAFT, with strong demand from the government for sub-national scale prediction, there is need for a coordinated effort by national government agencies and international partners to improve Nepal's crop forecasting system. As an important tool within NeKSAP, there is strong organizational support from the MoAD, DoA, and NARC, which has put forward CRAFT at the implementation level. However, for a full-scale implementation of CRAFT as a planning tool, the following recommendations for future work have been identified:

***Climate data*:** Further research on the climate aspects is highly important. Incorporation of DHM station data wherever possible and inclusion of reliable satellite estimates like CHIRPS, RFe, after adequate blending with station data, is one of the research aspects identified for the next phase. Capacity strengthening of CRAFT personnel and DHM on seasonal weather forecasting using CPT is also a necessity to provide reliable estimates at the sub-national scale.

Crop area data: Further research is required to identify different satellite-based products to identify real time crop area in Nepal. The implementation of SENTINEL-II, with support from ICIMOD, is one of the activities planned in the near horizon.

Capacity strengthening: Understanding the unavoidable risk of frequent turnover of government officials, the next phase for CRAFT is now being designed to meet the need for continued training to government staff and developing food-security analysts through regular training of university professors and students. The Agriculture and Forestry University has expressed a strong commitment to include crop modelling in its graduate curriculum and CRAFT is an integral part of it. The enhanced network of trained personnel and students will also help overcome the data constraints.

Formation of a Technical user group: A multi-stakeholder driven network for running CRAFT is envisioned as a technical user group. The group will be comprised of representatives from MoAD, DoA, DHM, NARC, FAO, IRRI, CIMMYT, AFU, TU, and so on, convening each season to run CRAFT and provide production estimates for the season. This will enhance the organizational coordination and will provide a solid basis to work in closer collaboration and share resources and ownership.

Appendix: MoAD and CRAFT wheat and rice production estimate time series

Year	Wheat			Paddy rice		
	Estimated production, tonnes			Estimated production, tonnes		
	MoAD	CRAFT	Bias, %	MoAD	CRAFT	Bias, %
1983	518,323	484,030	-6.62			
1984	551,213	593,887	7.74			
1985	565,059	507,285	-10.22			
1986	570,906	410,370	-28.12			
1987	579,952	430,220	-25.82			
1988	715,309	534,863	-25.23			
1989	814,347	934,919	14.81			
1990	835,763	818,809	-2.03			
1991	762,061	922,613	21.07	3,222,540	3,419,080	6.1
1992	765,019	860,495	12.48	2,584,900	2,884,276	11.6
1993	898,624	708,819	-21.12	3,495,590	3,570,612	2.1
1994	941,488	1,302,032	38.30	2,906,180	3,313,585	14.0
1995	1,012,925	1,238,336	22.25	3,578,830	3,960,125	10.7
1996	1,072,062	895,408	-16.48	3,640,860	3,595,277	-1.3
1997	1,030,448	1,086,797	5.47	3,699,770	3,839,296	3.8
1998	1,086,159	889,650	-18.09	3,834,290	3,849,530	0.4
1999	1,183,452	1,429,350	20.78	4,216,465	3,875,157	-8.1
2000	1,157,700	1,379,744	19.18	4,164,687	3,786,644	-9.1
2001	1,258,107	1,252,149	-0.47	4,132,600	4,071,326	-1.5
2002	1,344,049	1,319,964	-1.79	4,132,500	3,843,617	-7.0
2003	1,386,997	1,235,532	-10.92	4,455,722	4,215,583	-5.4
2004	1,442,172	1,475,941	2.34	4,289,827	3,948,562	-8.0
2005	1,393,811	1,357,659	-2.59	-	-	-
2006	1,514,944	1,617,869	6.79	3,680,839	3,451,530	-6.2
2007	1,571,920	1,508,038	-4.06	4,299,264	3,868,608	-10.0
2008	1,344,033	1,516,739	12.85	-	-	-
2009	1,556,578	1,499,910	-3.64	4,023,823	3,616,716	-10.1
2010	1,746,060	1,735,268	-0.62	4,460,278	3,616,800	-18.9
2011	1,845,945	1,930,934	4.60	-	-	-
2012	1,727,216	1,862,686	7.84	-	-	-
2013	1,883,172	1,976,445	4.95	4,788,612	4,349,543	-9.2
2014	1,975,607	1,994,598	0.96	-	-	-
2015	1,736,489	1,718,120	1.06	4,299,078	4,181,298	-2.7

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