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Computational modeling for pigeonpea yield prediction in an integrated farming system

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ABSTRACT

This paper deals with the discussion that how the integrated farming system (IFS) ver. 1.1 model has been developed simulating the entire farm based situations faced by innovative farmers of western Uttar Pradesh with desired technological modifications needed to boost the farmers' productivity and profitability on sustainable basis. Integration of pigeonpea crop and practically feasible farm enterprises, we can earn better net profitability with lesser annual cost of cultivation with overall holistic benefit- cost ratio under IFS ver. 1.1 model. These results reveal that induction of IFS principles and technological interventions on the basis of land use planning, the system can fetch better gains and livelihood through their farms. This model can act as an innovative tool to transform less remunerative farm production systems into highly remunerative systems using available farm resources to generate better farm gains on sustainable basis. Suggested model can also be useful in teaching processes involved in the systems and its behavior in response input variables. Calibration, verification, and validation are very important procedure to produce accurate simulation models.

Key words: Integrated farming system model, land use planning, productivity, profitability

Studies on crop production are traditionally carried out by using conventional experience-based agronomic research, in which crop production functions are derived from statistical analysis without referring to the underlying biological or physical principles involved. The application of correlation and regression analysis has provided some qualitative understanding of the variables and their interactions that were involved in cropping systems and has contributed to the progress of agricultural science (Kumar and Chaturevdi, 2009). However, the quantitative information obtained from this type of analysis is very site specific. The information obtained can only be reliably applied to other sites where climate, important soil parameters and crop management are similar to those used in developing the original functions. Thus, the quantitative applicability of regression based crop yield models for decision making is severely limited.

As knowledge is accumulated, results obtained from observation change from being qualitative to being quantitative and mathematics can be adopted as the tool to express biological hypotheses. Advances in computer technology have made possible the consideration of the combined influence of several factors in various interactions. As a result, it is possible to quantitatively combine the soil, plant, and climatic systems to more accurately predict crop yield. Thus, with the availability of inexpensive and powerful computer technology and with the growing popularity of the application of integrated systems to agricultural practices, a new era of agricultural research and development is emerging (Jones *et al.* 1993). In crop growth modeling, current knowledge of plant growth and development from various disciplines, such as crop physiology, agro-meteorology, soil science and agronomy, is integrated in a consistent, quantitative and process-oriented manner. Computerized decision support systems that allow users to combine technical knowledge contained in crop growth models with economic considerations and environmental impact evaluations are now available. Lack of awareness about model structure, possibilities and limitations have been identified as hindrance to model application in our society (Sunil Kumar *et al.* 2015).

Achieving maximum crop yield at minimum cost is one of the goals of agricultural production. Early detection and management of problems associated with crop yield indicators can help increase yield and subsequent profit. By influencing regional weather patterns, large-scale meteorological phenomena can have a significant impact on agricultural production. Predictions could be used by crop managers to minimize losses when unfavorable conditions may occur. Additionally, these predictions could be used to maximize crop prediction when potential exists for favorable growing conditions. Prediction of crop yield mainly strategic crop such as pigeonpea has always been an interesting research area to statistical, as it is important in national and international economic programming. Irrigated farming crop production, apart from relationship to the genetic of cultivator, adaphic terms and the management during the growing season etc. is severely depend to climatic events (Sunil Kumar 2015).

Pigeonpea plays an important role in food security, balanced diet and alleviation of poverty because it can be used in diverse ways as a source of food, feed, fodder (Rao *et al.* 2002), fuel wood, rearing lac insects (Zhenghong and and Fuji, 1997) hedges, windbreaks, soil conservation, green manuring and roofing. It is a major source of protein to about 20% of the world population and is an abundant source of minerals and vitamins (Saxena *et al*. 2007). Its abundance in protein makes it an ideal supplement to traditional cereal-based diets of resource poor farmers that are generally protein-deficient. The perennial nature of pigeonpea allows farmers to take multiple harvests with surpluses traded in both national and international markets. It is imperative to design and implement strategies to develop climate smart technologies that enable to generate quality employment and feasible to implement at small and marginal farmers which constitutes about 93% of the farming community of the country. Therefore, computational modeling for farming systems is a valuable approach to address the problems of sustainable economic growth of farming communities which will certainly play a key role for bringing evergreen agricultural revolution in the country (Sunil Kumar *et al.* 2014).

MATERIALS AND METHODS

The field experiments were established during 2013 and 2014 at Indian Institute of Farming System Research Modipuram, Meerut research farm (at 29° 08', N latitude and 77° 41' E longitude at an altitude of 237 m above mean sea level) Utter Pradesh, India. The region has a semi-arid sub-tropical climate with an average annual temperature of 16.8^{0}C. The highest mean monthly temperature (38.9^{0}C) is recorded in May, and the lowest mean monthly temperature (4.5^{0}C) is recorded in January. The average annual rainfall is about 665 to 726 mm (constituting 44% of pan evaporation) of which about 80% is received during the monsoon period. The predominant soil at the experimental site is classified as sandy loam in texture. Soil samples for 0–15 cm depth at the site were collected and tested prior to applying treatments and the basic properties were low available nitrogen, low organic carbon, and medium in available phosphorus, available potassium and alkali in reaction.

Statistical analysis: The data generated through the field experiment for two seasons were processed and analyzed individually as well as for pooled basis to ascertain the high yielding cultivar and the optimum date of sowing with respect to grain, straw and above ground biomass yield. Comparisons were made between simulated data of various parameters *viz.*, yield, and periodic dry matter, above ground biomass production, periodical and maximum, test weight, harvest index, grains per pod, and test grain weight and their corresponding observed data through regression analysis (Rai, T and Chandrahas 1997).

Validation of the model: Validation is the comparison of the results of model simulations with observations from crop that was not used for the calibration. A model should be rigorously validated under widely differing environmental conditions to evaluate the performance of major processes in addition to its ability to predict yield (Timsima and Humphreys, 2003). Before any model can be used with confidence, adequate validation or assessment of the magnitude of the errors that may result from its use should be performed. Model validation, in its simplest form is a comparison between simulated and observed values (Keating, B.A 2003).

Beyond comparisons, there are several statistical measures available to evaluate the association between predicted and observed values. Among them correlation coefficient (r) and its square, the coefficient of determination (R^2) are widely used parameters. Willmott 1982 has pointed out that the main problem with this analysis is that the magnitudes of r and R^2 are not consistently related to the accuracy of prediction where accuracy is defined as the degree to which model predictions approach the magnitudes of their observed counterparts.

IFS SIMULATOR ver.1.1 model: A computer based crop model IFSS (Integrated Farming Systems Simulators) was used to simulate the growth, development and yield of pigeonpea under middle Meerut agro-climatic region by taking into account the effects of weather, management and genetics. Since the focus of this research is on performance of selected cultivar and applications of this model under middle Meerut agro-climatic region, therefore grain yield, test weight, pod initiation, flowering stage and physiological maturity was switched off during simulation. Since the initial configuration of the model was suited to simulate the performance of longer duration cultivar of crop, it couldn’t be fitted for above selected cultivar under this agro-climatic region as such. Thus for making the model suited to the variety of pigeonpea being grown under the agro-climatic conditions of this region, lot of efforts were made to create the required input files and to modify several initial values pertaining to the weather, soil, genotypes and management practices. Minimum crop performance data set are required for determining the values of the phonology coefficients initially and then the values of the coefficients describing growth and grain development include dates of emergence, beginning of grain filling, maturity duration, grain yield, above ground biomass and grain weight. The procedure for determining genetic coefficients involved in running the model using a range of values of each coefficient, in the order indicated above, until the desired level of agreement between simulated and observed values was reached. Iterations for the coefficients were stopped when the agreement reached ±10 %. For the present study the cultivar genetic coefficients based on field experimental data of first crop season *Kharif*, 2013 for UPAS-120 cultivar of pigeonpea had been carried out by trial and error as per Hunt's method.

IFSS ver.1.1 consists of many different applications, including data programs, crop simulation models and analysis programs for Agro-technology transfer. The following is a very brief description of IFSS models (Fig. 1 & 2). The main elements in the design techniques are identification of critical inputs and their interactions, software engineering for developing algorithm, calibration, verification and validation of the developed computational model.

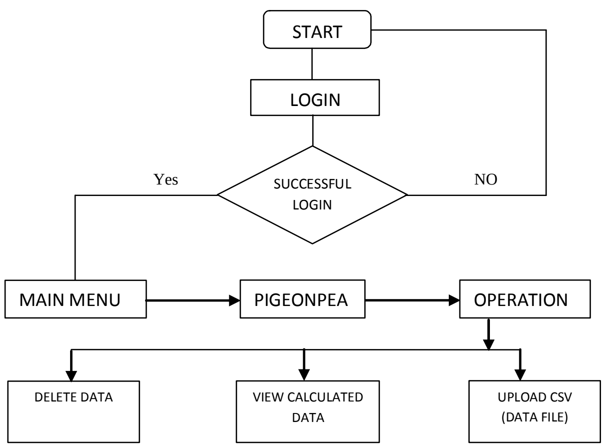

Fig.1. Frontend Flowchart of IFSS Model.

Input identification and their interactions: This phase defines the critical inputs and their interaction among themselves for optimum output. During identification of the inputs, it is advised to take the minimum but most critical for the sake of simplicity of the model and to establish the interactions among the selected inputs. Interaction of the inputs conceptualizes the mechanism and behavior of the systems for a particular set of objectives.

Software engineering for developing algorithm: After establishing the concept behind a set of objectives, algorithmization of the interaction is the next step for developing the computational model using the concept of software engineering.

Calibration, verification and validation: Shaalan Khaled *et al.* 2004 studied that these three steps, calibration, verification and validation are the important steps to bring accurate simulation models. A base model should be created and calibrated so that it matches the area being studied. The calibrated model should then be verified to ensure that the model is operating as expected based on the inputs. Verification is a set of techniques for determining the validity of computational models predictions relative to a set of real data. To verify a model, the models predictions are compared graphically or statistically with the real data.

RESULTS AND DISCUSSION

Table 1 revealed that higher yield was obtained during 2013 as compared to 2014 due to favorable climatic conditions in the year of study. Treatment T_2 obtained statistically higher grain yield (770 and 315 kg ha^{-1}) followed by T_1 (761 and 312 kg ha^{-1}) during the years of study. Among all the treatments T_3 recorded lowest grain yield during experimentation. Similar trends were found in biomass yield during the years of study.

Table 1. Yield and biomass of pigeonpea during *kharif* 2013 and 2014

Treatments	Grain yield (kg ha^{-1})			Biomass yield (kg ha^{-1})		
	2013	2014	Mean	2013	2014	Mean
T_1	761	312	537	1385	3437	2411
T_2	770	315	543	1391	3438	2414
T_3	760	307	534	1387	3437	2412

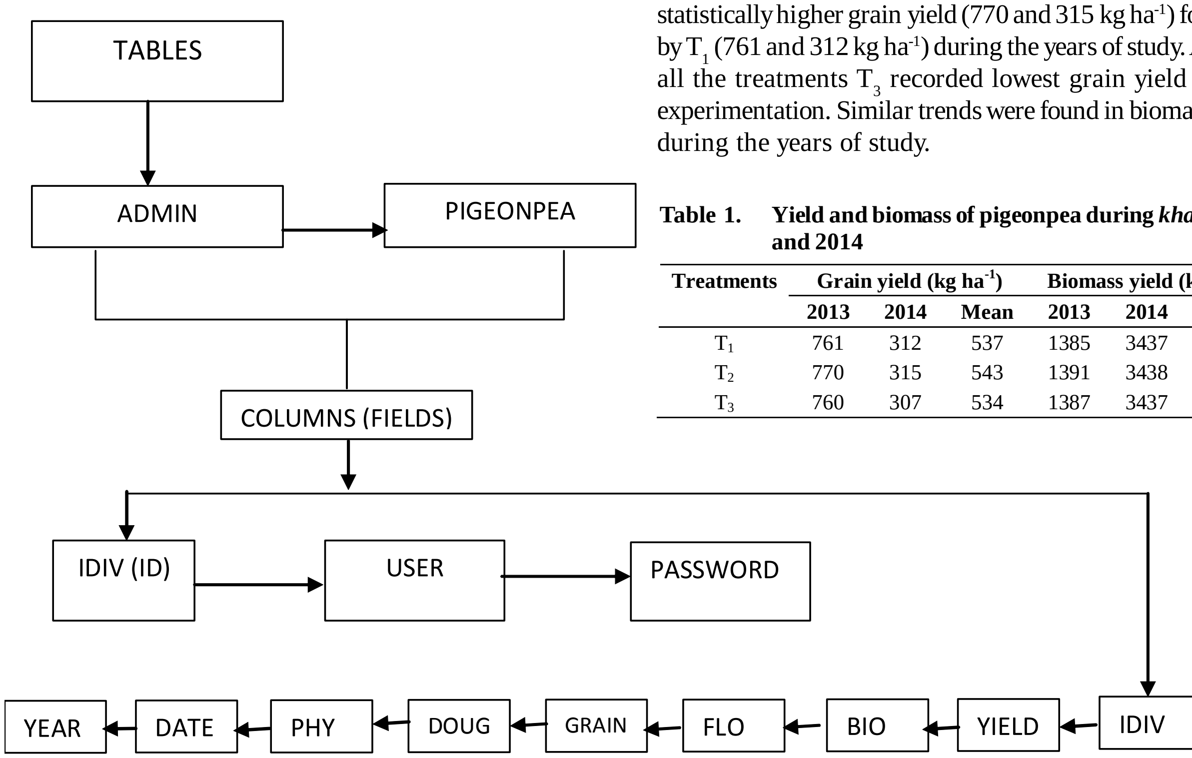

Fig.2. Database Structure Flowchart of IFSS Model.

Table 2. Phonological parameters of pigeonpea

Treatments	Flowering (Days)			Pod formation (Days)			Grain filing stage (Days)			Dough stage (Days)			Physiological maturity (Days)		
	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean	2013	2014	Mean
T1	95	90	93	115	107	111	125	114	120	143	126	135	172	146	159
T2	98	90	94	117	107	112	128	117	123	147	129	138	175	149	162
T3	93	86	90	113	104	109	124	111	118	142	123	132	170	144	157

Table 2 embodied that treatment T_2 required more days (98 days) to flowering followed by T_1 (95 days) and T_3 (93 days) during first year *i.e.*, 2013. However, during second year (2014) treatments T_2 and T_1 obtained similar days to flowering (90 days). During experimentation average days taken to pod formation were 112, 111 and 109 days in treatments T_2, T_1 and T_3, respectively.

Grain filing, dough and physiological maturity stage revealed that treatment T_2 recorded statistically more days (128,147,149 days) followed by T_1 (125, 143, 146 days) and T_3 (124, 142, 144 days) during the years of study (Table2).

Table 3. Regression models for estimation of the grain yield of pigeonpea

Model		Coefficients: Unstandardized Coefficients	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	769.914	62.14		12.39	0
	Biomass	-0.194	0.005	-0.877	-35.715	0
	Physiological maturity	2.68	0.561	0.16	4.777	0
	Pod formation	-1.741	0.56	-0.04	-3.109	0.008

Out of 6 parameters related grain yield of pigeonpea *viz*, biomass yield, flowering, milking stage, dough stage and physiological maturity significantly contribute in the determination of grain yield of pigeonpea, the coefficient of determination R^2=0.912 is calculated following the stepwise regression analysis. The regression equation {(Grain Yield (kg/ha) =769.914*(Biomass)-0.1948* (Physiological maturity) +2.68* (Pod formation)-1.741)} was fitted in the model for development of the software for decision support systems as a pigeonpea component/ module [Table 3]. The results are in the conformity with Idnani and Gautam, 2008.

Comparison of model for Pigeonpea: On the basis of Table 1 and 2 result was found better for other statistically software analysis of Pigeon-pea crop. However, model used in the experimentation was found much better for other excel programme because accuracy of the existing model result was R^2=0.912 than other model accuracy due to R^2=0.879. The coefficient of determination was calculated under the following steps by regression analysis parameters *viz*, test weight, PI, flowering, milking stage, dough stage and physiological maturity that affect the significant contribution in the determination of Pigeonpea yield. Under the study area model used during experimentation was performed better accuracy as compared to other software. However, existing model is used more easy to predict the experimental finding elaborate or explained perfectly the crop performance.

Farmers were benefitted by the use of such model on their fields, use of models in farming was done to increase productivity and in turn livelihoods. Modeling technology like IFSS (Integrated Farming System Simulator ver.1.1) was developed for Pigeonpea crop computational modeling yield predictions in integrated farming system, which benefitted the entire farmer community in western Uttar Pradesh and also became popular in other regions of India.

CONCLUSION

Crop husbandry and livestock rearing are integral part of western Uttar Pradesh farming. Thus, integrated farming is done by resource management to earn their livelihood. Majority of farmers practice inadequate crop management with low productivity and profitability. Thus, development of an economically viable and practically feasible IFS model of ver.1.1 acted as an innovative tool for knowledge up-gradation for higher productivity and profitability under IFS model through pigeonpea crop to fetch better livelihood on sustainable basis and equip them with innovative farm technology. As a research tool, model development and application can contribute to identify gaps in our knowledge, thus enabling more efficient and targeted research planning. Models that are based on sound crop data are capable of supporting extrapolation to alternative cropping cycles and locations, thus permitting the quantification of temporal and spatial variability. An intensely calibrated and evaluated model can be used to effectively conduct research that would in the end save time and money and significantly contribute to developing sustainable agriculture that meets the country needs for food.

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REFERENCES

Idnani LK and Gautam HK. 2008. Water economization in summer greengram (*Vigna radiata* var. *radiata*) as influenced by irrigation regimes and land configurations. Indian Journal of Agricultural Sciences **78:** 214-219.

Jones JW, Penning de Vries, Teng P and Metsellaar K. 1993. Decision support systems for agricultural development. Systems approach for agricultural development. Kluwer Academic Publishers, Dordrecht, the Netherlands. Pp 459-471.

Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth D, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, Mclean G, Verburg K, Snow V, Dimes JP, Silburn M, Wang E, Brown S, Bristow KL, Asseng S, Chapman S, Mccown RL, Freebairn DM and Smith CJ. 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18: 267-288.

Kumar Sunil, Shamim Mohammad, Mamta, Gangwar B and Agarwal RP. Computational modeling and emerging trend in agriculture 2015. 2nd International Conference on Computer for sustainable Global Development", 11th -13th March, 2015. Bharati Vidyapeeth's Institute of computer and management (BVICAM), New Delhi (INDIA).

Kumar Sunil**,** Shamim Mohammad, Mamta, Gangwar B and Agarwal RP. 2014. Computational Modelling and Intelligence in Agriculture. Journal Farming Systems Research & Development **20(1):** 52-59.

Kumar Sunil**,** Shamim Mohammad, Mamta, Gangwar. B and Agarwal RP. 2015. Emerging trends and statistical analysis in computational modeling in agriculture. International Journal of Electronics Communication and computer engineering **6:**171-174.

Kumar R and Chaturevdi S. 2009. Crop Modeling: A Tool for Agricultural Research. Agropedia.

Rai T and Chandrahas. 1997. Composite weather index for the forecast of rice yield. Journal Indian Society of Agricultural Statistics **50:** 328.

Rao SC, Coleman SW and Mayeux HS. 2002. Forage production and nutritive value of selected pigeon-pea lines in the southern Great Plains. Crop Science **42:** 1259-1263.

Saxena KB, Srivastava RK, Wanjari KB, Gowda CLL, Sarode SV, Singh IP, Kumar S, Kumar RV and Ali M. 2007. Hybrid Pigeonpea-The Seeds of Excellence. Paper Presented at the National Symposium on Legumes for Ecological Sustainability: Emerging Challenges and Opportunities. IIPR, Kanpur, India.

Shaalan Khaled, El-Badry Mona and Rafea Ahmed. 2004. A multiagent approach for diagnostic expert systems via the internet. Expert Systems with Applications **2:**1-10.

Timsima J and Humphreys E. 2006. Applications of CERES-Rice and CERES-Wheat in research, policy and climate change studies in Asia: a review. International Journal of Agricultural Research **1(3):** 202-225.

Willmott. 1982. Validation of the model. Chapter No. 8 in CERES-Wheat x book, Draft No. 1.

Zhenghong L and Fuji L. 1997. Development prospect on pigeon-pea resources for fodder and food. Pages 127–130 in Papers collection of deliberating conference - Industry and Market Development of Special Animals and Plants in Yunnan. Kunming, China: Scientific and Technological Publishing House of Yunnan.