Original article

Production efficiency based land-use planning for almond – A new modus operandi

A. Sharma[1,a], N. Ahmed[1], S. Kumar[1], D. Kumar[1], O.C. Sharma[1] and S.A. Khan[2]

[1] ICAR-Central Institute of Temperate Horticulture, Old Air Field, KD Farms, Rangreth-190007, Jammu and Kashmir, India
[2] Indian Agricultural Research Institute, Pusa, New Delhi-110012, India

Summary

Introduction – **A clear perception of the production efficiency of land is necessary for its management, planning, and development. On-site experimentation for determining the production efficiency and land aptness of a site for a perennial crop, such as almond, is not feasible. The lack of planning and management, low profitability, and lack of awareness of land aptness have caused the substitution of the almond crop by other crops in the cold humid regions of north-west Himalayas. Considering the aforementioned challenges, the present investigation was carried out to develop an efficient methodology to prevent any substitution of the almond crop.** *Materials and methods* – **Twenty standardized indicator parameters, including soil, plant variety (traditional or improved), climatic, and geographic parameters were used to develop and evaluate the relative production efficiency index ($RPEI_a$) for almond. This index was further used to generate models for land use planning and yield prediction of almond.** *Results and discussion* – **The reasons for substitution were determined through exhaustive surveys, and on the basis of these reasons, a methodology focusing on production efficiency was developed. A new methodology to standardize the indicator parameters influencing fruit yield was developed. Furthermore, $RPEI_a$-based empirical models for land-use planning and yield prediction were developed. The sustainability yield index was computed and its relationship with the $RPEI_a$ was determined.** *Conclusion* – **The indices and models developed in the present investigation should facilitate the production efficiency evaluation of an area, provide a yield prediction and a land-use planning for the almond crop.**

Keywords
India, Himalaya, almond, *Prunus dulcis*, agroecology, land management, land productivity

Résumé

Planification de l'utilisation des terres pour l'amandier par efficacité en production – Un nouveau mode opératoire.

Introduction – **Une perception claire de l'efficacité en production de la terre est nécessaire pour sa gestion, sa planification et son développement. L'expérimentation *in situ* pour déterminer l'efficacité de production et l'aptitude du sol d'un site pour une culture pérenne comme l'amandier n'est pas réalisable. L'absence de planification et de gestion, la faible rentabilité et le manque de prise de conscience de l'aptitude d'agricole d'une terre ont provoqué la substitution de la culture d'amandes par d'autres cultures dans les régions froides et humides du nord-ouest des Himalayas. Compte tenu des défis susmentionnés, la présente étude a été menée en vue de développer une méthodologie efficace pour prévenir la substitution des amandiers.** *Matériel et méthodes* – **Vingt paramètres d'indicateurs standardisés, y compris les paramètres du sol, des plantes (variétés traditionnelles ou améliorées), du climat et géographiques ont été utilisés pour développer et évaluer l'indice d'efficacité relative en production d'amandes ($RPEI_a$). Cet indice a ensuite été utilisé pour générer des modèles pour l'aménagement du territoire et la prédiction du rendement en fruits des amandiers.** *Résultats et discussion* – **Les raisons de la substitution des cultures ont été déterminées par des enquêtes exhaustives et, sur la base de ces raisons, une méthodologie axée sur l'efficacité de la production a été développée. Une nouvelle méthodologie de normalisation des paramètres indicateurs influençant le rendement en fruits a été développée. En outre, des modèles empiriques basés sur le $RPEI_a$ pour l'aménagement du territoire et la prédiction du rendement ont été développés. L'indice de rendement durable a été calculé et sa relation avec le $RPEI_a$ a été déterminée.** *Conclusion* – **Les indices et les modèles développés dans la présente étude devraient faciliter l'évaluation de l'efficacité en production d'une zone, fournir une prédiction du rendement**

Significance of this study

What is already known on this subject?

- The relative production efficiency index has proved to be a useful indicator to make appropriate and suitable decisions on land site use based on return on input.

What are the new findings?

- Empirical models based on relative production efficiency for land use planning and yield prediction of almond have been developed for the first time.

What is the expected impact on horticulture?

- The indices and models developed help evaluate the production efficiency of an area and are functional in predicting almond yields, planning land use suitability and crop management.

[a] Corresponding author: magotra_sonu@rediffmail.com.

et une planification de l'utilisation des terres pour la culture de l'amandier.

Mots-clés
Inde, Himalaya, amandier, *Prunus dulcis*, agroécologie, utilisation des terres, productivité foncière

Introduction

Considering the highly competitive international environment, assessing a country's production potential is necessary. High-value horticultural production has been indicated as a sector that can provide real opportunities for enhancing farm incomes and reducing poverty (Bhattacharyya, 2011) in developing countries such as India. Furthermore, to balance the future demand and supply, particularly of horticultural crops, research should focus on increasing production from fixed land area while simultaneously reducing the environmental effects on production (Godfray *et al*., 2010). Thus, increasing food or fruit production through proper land-use management has been the major focus in the pursuit of sustainable development (Thapa and Yila, 2012).

Almond (*Prunus dulcis* L.) is a high-value horticultural nut crop. In the Indian context, almond cultivation warrants greater attention from researchers and planners than it currently receives. Because of the high demand and low production of the almond crop (Varmudy, 2011) in India, import meets a major portion of the almond demand. Moreover, this demand is continuously increasing due to the increase in almond consumption. In India, almond is mostly cultivated in the cold humid regions of the north-west Himalayas. Almond from this region is reputed as being one of the choicest fruits (Pandit and Sharma, 2015). However, in last five to six years (2011 onwards), the substitution of almond with other crops, such as apple, in orchards has become a major concern. The area under almond cultivation has reduced by 7.65% (Pandit and Sharma, 2015) in three years (2010–2012). Few researchers have conducted preliminary studies to determine the reasons for the shift in cultivation (Pandit and Sharma, 2015).

A survey of the almond growing cold humid regions of the northwest Himalayas revealed that 61% of the farmers, who have shifted from almond cultivation to that of other crops, stated reasons that are directly or indirectly related to 'production efficiency based land-use planning and management'. The stated reasons are: climate and weather risks (10%), lack of awareness regarding land-use potential (18%), senile orchards (12%), unsystematic land use (9%), and degraded orchards (12%). Pandit and Sharma (2015) also reported a 'lack of management and planning' as one of the problems forcing the almond growers of the region to shift to cultivation of other crops, thereby reducing the acreage under this crop.

Addressing the afore-mentioned challenges or problems will require the integration of several components of horticultural production combined with a complete understanding of the interaction of these components (Skirvin, 2011). The entire almond growing area in the north-west Himalayan regions is rainfed, and maintaining soil and crop productivity in rainfed areas is a major challenge (Srinavasarao *et al*., 2014). Therefore, to reduce the effort and cost involved in maintenance, proper land-use planning at the onset of plantation should be encouraged. Previously, researchers focused on improving individual components of horticultural production, and did not consider, in detail, the possible effects of changes in the component of interest on the other components of the system (Dominguez *et al*., 2010). Hence, the knowledge of plant responses to environmental, soil, and physiographic components and conditions is a key factor for proper land-use planning for ensuring optimum production. The production of almond is strongly influenced by several factors, including climatic factors, such as rainfall (Dorfman *et al*., 1988) and temperature; soil factors, such as fertility (Dorfman *et al*., 1988) and availability of nutrients (Nyomora and Brown, 1999); geographical factors, such as altitude; physiographic and varietal factors (Lamp *et al*., 2001). Furthermore, on-site measurement of crop performance is tedious and time-consuming. A waiting period of 6 to 8 years is required to assess the almond yield and economic returns for almond producers. Hence, developing and testing of models to plan proper land-use for almond cultivation is necessary. Thus far, no mathematical expressions or models have been proposed for the almond crop.

According to McPhee (2009), mathematical or empirical modelling plays an integral role in the development of agricultural systems. Models (whether mathematical or conceptual) are powerful tools to test hypotheses, as well as to synthesize knowledge for describing and understanding complex systems for comparing different scenarios (Marcelis *et al*., 1998). Mathematical models have been a significant focus of researchers in agricultural systems over the past four decades (Fleisher, 2002). Models may be used in planning of production strategies and prediction of yields (Lentz, 1998). Some crucial modelling work is currently in process (Grundy and Turner, 2002). The interest in modelling of yield (Grundy and Turner, 2002) and land-use planning as well as management related to horticultural crops is increasing. In fact, crop modelling has become one of the major research tools in horticulture (Gary *et al*., 1998).

Considering the need of empirical models for horticultural crops and the afore-mentioned complexities, the present investigation attempts to provide researchers, scholars, policymakers, and fruit growers with access to an extensive knowledge base of production efficiency, land-use planning, and yield predictions for almond cultivation through various empirical models. These models are applicable not only to the cold humid regions of the north-west Himalayas but also to all almond growing areas extending from sub-tropical to temperate regions of the world. The models as well as the methodology developed in the present investigation can facilitate prediction of yield and planning land use (for new and established orchards) for the almond crop in the entire almond-growing region. In some Mediterranean regions, a decline in nut yield has been reported, and the decline has been attributed to climatic parameters (Murua *et al*., 1993). Here, in the afore-mentioned models, all such parameters and their potential influences have been included. Furthermore, the almond crop has several varieties, which have different chilling requirements and can be grown from sub-tropical to temperate regions. The models developed will be applicable for such varieties too.

The present study was carried out with three major objectives: 1) to design a new methodology to standardize indicator parameters for evaluating production efficiency of a location for growing and managing almond crop; 2) to develop a production efficiency based model for land use planning of the almond crop; and 3) to develop a yield prediction model for the almond crop.

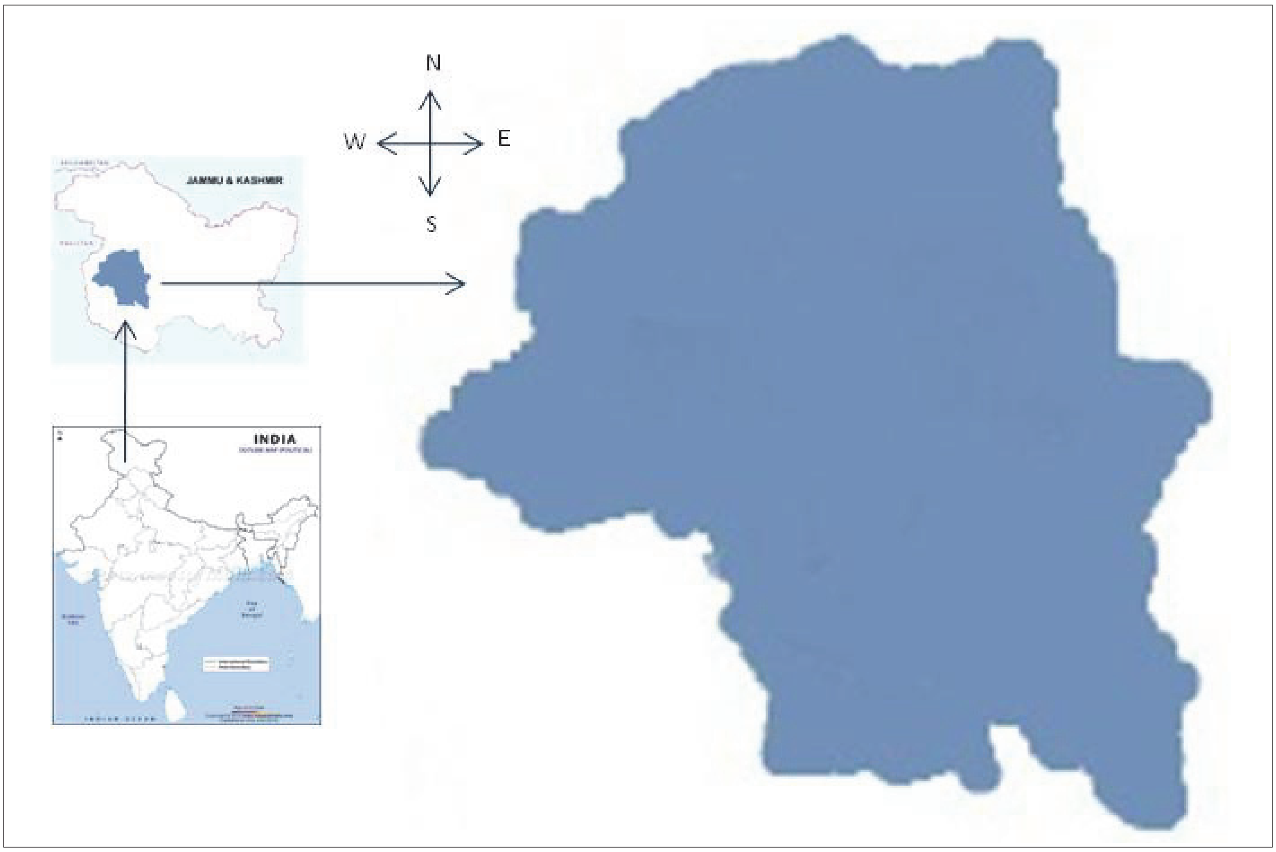

FIGURE 1. Cold humid region of the northwest Himalayas, India.

Materials and methods

The present investigation was carried out in the almond-growing cold humid region of the northwest Himalayas extending from 32°30" to 34°30" North latitude and 74° to 75°30" East longitude (Figure 1). Agro-climatically, this region is classified under the temperate zone at an altitude ranging from 1,500 to 2,500 m a.s.l. The major almond-growing cold humid regions included in the present investigation are Srinagar, Pulwama, Budgam, Anantnag, Shopian, Kulgam, Ganderwal, Uri, and Bandipora. The parameters used to evaluate the relative production efficiency index ($RPEI_a$) included soil physico-chemical parameters – textural class, pH, organic carbon (OC), available nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), boron (B), zinc (Zn), iron (Fe), cation exchange capacity (CEC); soil microbial biomass (SMB); weather parameters – cropping season rainfall (CSR), cropping season temperature (CST), wind speed during bloom (WS), accumulated growing degree days (GDD); geographic parameters – slope and altitude; age of the trees or orchard; and varieties (traditional or improved).

Primary and secondary data were used in this study. Primary data were generated through the analysis of soil samples collected from 28 locations (*n* = 560) representing almond-growing areas of the northwest Himalayas. These soils were analysed for various soil physical, chemical and biological properties using standard procedures. Corresponding climatic, geographical, varietal, and age-related data (age of the orchard or trees) were also recorded. Secondary data of the same parameters were collected from different sources of literature that include horticultural and other related reports, thesis, statistical reports, and research papers.

Standardization and weight assigning to indicator parameters

In order to develop and evaluate relative production efficiency index for almond ($RPEI_a$), indicator parameters were standardized and weights were assigned to each of these parameters on the basis of (r) values or coefficient of correlation (irrespective of positive or negative correlation) obtained after correlating these indicator parameters with yield, as per the standard statistical procedure. All these (r) values were classified into six classes as per the magnitude of influence of these values as given below:

Class I: > 0.900
Class II: 0.800 – 0.899
Class III: 0.700 – 0.799
Class IV: 0.600 – 0.699
Class V: 0.500 – 0.599
Class VI: 0.400 – 0.499

The lowest value of each class was designated as base value (B_v) of that particular class. For assigning weights to each of the indicator parameters (Table 1) the following equations (1 to 3) were developed and used:

$$\text{Weight} = (B_v - 0.1)/10 \qquad \text{(Eq. 1)}$$
if (r) > 0.700 or if significant at 0.001 level of significance

$$\text{Weight} = (B_v - 0.2)/10 \qquad \text{(Eq. 2)}$$
if (r) = 0.500 to 0.699 or if significant at 0.05 level of significance

$$\text{Weight} = (B_v - 0.3)/10 \qquad \text{(Eq. 3)}$$
if (r) = 0.400 to 0.499 or if not significant but (r) > 0.400

Table 1. Assignment of weights to indicator parameters, for almond crop, based on the coefficient of correlation (r) and base values. Class I: >0.900, Class II: 0.800–0.899, Class III: 0.700–0.799, Class IV: 0.600–0.699, Class V: 0.500–0.599, Class VI: 0.400–0.499; lower value of each class is the base value of that class.

Parameters	Correlation coefficient (r) values* for nut yield	Class	Base value (B_v)	Weight
Textural class	0.807	II	0.800	0.07
Slope (degree)	0.890	II	0.800	0.07
Altitude (m)	0.884	II	0.800	0.07
Age of tree or orchard (years)	0.784	III	0.700	0.06
pH	0.610	IV	0.600	0.04
OC (%)	0.930	I	0.900	0.08
Av. N (kg ha^{-1})	0.719	III	0.700	0.06
Av. P (kg ha^{-1})	0.761	III	0.700	0.06
Av. K (kg ha^{-1})	0.776	III	0.700	0.06
Ca (meq 100 g^{-1} soil)	0.572	V	0.500	0.03
Boron (ppm)	0.543	V	0.500	0.03
Zinc (ppm)	0.421	VI	0.400	0.01
Iron (ppm)	0.466	VI	0.400	0.01
CEC (C mol kg^{-1})	0.667	IV	0.600	0.04
Microbial biomass (µg g^{-1} soil)	0.527	V	0.500	0.03
Cropping season rainfall (mm)	0.729	III	0.700	0.06
Cropping season temperature (°C)	0.856	II	0.800	0.07
Wind speed during bloom (km h^{-1})	0.769	III	0.700	0.06
Accumulated GDD	0.740	III	0.700	0.06
Variety (traditional/improved)	0.504	V	0.500	0.03

* Irrespective of positive or negative correlation.

where B_v is the base value of the class in which the coefficient of correlation falls. Only the parameters or variables having (r) value more than 0.400 were considered as indicator parameters. The equations were developed after exhaustive analysis and conducting separate experiments for determining the influence of each of these parameters on yield.

Classification and allotment of marks

After assigning weights the indicator parameters were divided into four classes: Class I (Most suitable for almond crop), Class II (Suitable with slight limitations), Class III (suitable with more serious limitations) and Class IV (very less suitable). Marks 0.4, 0.3, 0.2 and 0.1 were allotted to the classes as per their suitability levels (Table 2). Classes for soil physical, chemical and biological parameters were standardized as per the rating chart based on soil test values, whereas classes for climatic, physiographic and varietal parameters were standardized as per the historic as well as experimental data related to influence of these parameters on almond yield. Although these classes are generally more crop specific than the location specific but the values or range in these classes are subject to minor variation as per the local conditions. Varietal classes have broadly been divided into two major classes: improved and traditional (Table 2).

This standardization and weight assigning methodology can be followed for any fruit crop especially for fruit crops of temperate regions. The indicator selected here in this investigation (for almond crop) may not be the same for other crops because the indicator parameters may have different association with the fruit yields of different crops.

Sustainability yield index

Almond productivity was calculated through a sustainable yield index (SYI). The SYI was computed to offset any annual variation in yield (Srinavasarao *et al.*, 2014) and also to highlight specific performance of a variety during the last few years. Furthermore, its relation with production efficiency index was also determined. The SYI was calculated using the following equation:

$$SYI = Y\text{-}\ \sigma\ /\ Y_{max}$$

where Y is the estimated average yield of a variety across the years, σ is its estimated standard deviation, and Y_{max} is the observed maximum yield during the years (Singh *et al.*, 1990).

Statistical analysis

A large dataset was statistically analyzed exhaustively as per the method described by Cochran and Cox (2000). The correlation and other mathematical relationships were developed using SPSS and MS Excel software.

Results and discussion

Since almond production had been the economic mainstay of the cold humid regions of north-west Himalayas, almond producers in these regions have been making efforts to increase almond productivity through both indigenous and introduced land management practices. The use of the $RPEI_a$ can facilitate attempts to increase almond productivity.

Table 2. Standardisation of indicator parameters to evaluate relative production efficiency index for almond ($RPEI_a$) in the cold humid regions of the northwest Himalayas.

Parameter	Weight (W_i)	Class I	Class II	Class III	Class IV
Textural Class	0.07	Loam	Sandy loam, Clay loam	Sandy, Clay	Grit
Slope (degree)	0.07	< 2	2-8	8-20	> 20
Altitude (m)	0.07	1500-2000	1,400-1,500, 2,000-2,300	1300-1400, 2300-2500	< 1300, > 2500
Age of tree or orchard (years)	0.06	8-15	6-8, 15-20	4-6, 20-25	< 4, > 25
pH	0.04	6.0-6.75	5.6-6.0, 6.75-7.3	5.3-5.6, 7.3-7.6	< 5.3, > 7.6
OC (%)	0.08	> 0.75	0.51-0.75	0.40-0.50	< 0.40
Av. N (kg ha^{-1})	0.06	> 560	400-560	280-400	< 280
Av. P (kg ha^{-1})	0.06	> 25	19-25	10-18	< 10
Av. K (kg ha^{-1})	0.06	> 280	201-280	120-200	< 120
Ca (meq 100 g^{-1} soil)	0.03	> 2.5	2.0-2.5	1.5-2.0	< 1.5
Boron (ppm)	0.03	0.80-1.0	0.70-0.80	0.5-0.70	< 0.5
Zinc (ppm)	0.01	> 1.2	0.81-1.2	0.6-0.80	< 0.6
Iron (ppm)	0.01	> 7.5	6.1-7.5	4.5-6.0	< 4.5
CEC (C mol kg^{-1})	0.04	> 16	13-16	8.0-12	< 8.0
Microbial biomass (μg g^{-1} soil)	0.03	300-500	200-300, 500-600	100-200, 600-700	< 100, > 700
Cropping season Rainfall (mm)	0.06	170-240	100-170, 240-350	50-100, 350-400	< 50, > 400
Cropping season Temperature (°C)	0.07	18.5-22.5	16-18.5, 22.5-24	12-16, 24-28	< 12, > 28
Wind speed during bloom (km h^{-1})	0.06	< 4	4-20	20-45	> 45
Accumulated GDD	0.06	1,550-1,650	1,450-1,550, 1,650-1,750	1,350-1,450, 1,750-1,850	< 1,350, > 1,850
Marks (M)		0.4	0.3	0.2	0.1

Parameter	Weight (W_i)	Class I		Class II		Class III		Class IV		
		Improved								Traditional
Varieties (traditional/improved) *Traditional:* seedlings *Improved:* 'Pranyaz', 'Merced', 'Waris', 'Makhdoom', 'IXL', 'Shalimar', 'Primorskij', 'California' 'Paper Shell'	0.03	$Variety_1$	$Variety_2$	$Variety_3$	$Variety_4$	$Variety_5$	$Variety_6$	$Variety_7$	$Variety_8$	
Marks (M)		0.40	0.37	0.35	0.33	0.30	0.25	0.20	0.17	0.10

In case exact information regarding the improved variety is not available average marks for such improved variety is 0.31; In case of no information about the variety (whether improved or traditional), average marks for all the varietal classes (*i.e.*, 0.29) are considered.

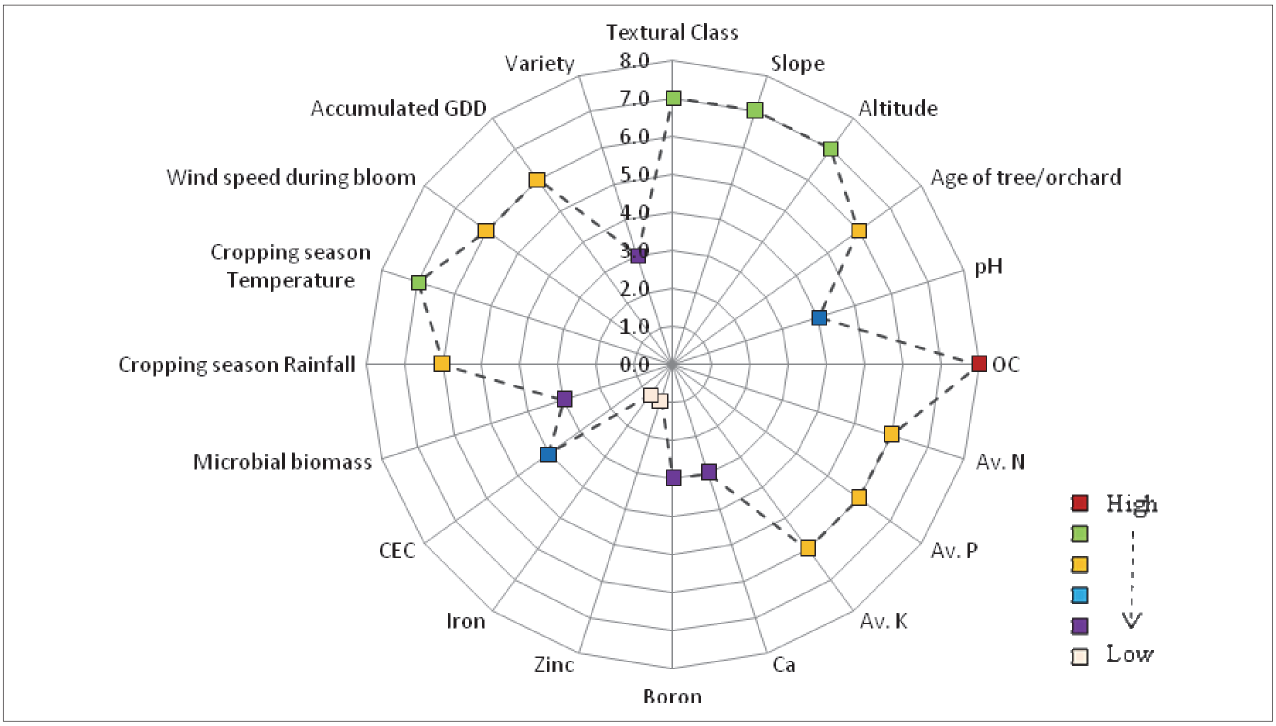

Figure 2. Influence intensity of indicator parameters, higher percentage influence (outer orbit) to lower percentage influence (towards core) on production efficiency of almond (*Prunus dulcis* L.) in the cold humid regions of the northwest Himalayas.

Relative production efficiency index for almond ($RPEI_a$)

A new and advanced technique, based on various soil, climatic, geographic, and crop parameters (indicator parameters) was developed to counter the problems related to land-use planning and management, which most almond growers of the northwest Himalayan regions are facing. To determine the contribution of various indicator parameters to production efficiency responsible for the declining productivity, the influence intensity of these parameters in almond-growing cold humid regions of the northwest Himalayas was assessed (Figure 2). Organic carbon, which is on the outer orbit, was observed to have the most intense influence and this can be attributed to its high coefficient of correlation (r) value. The high value of (r) may be because of its vital role in governing the cycling and availability of plant nutrients and the functioning of the soil system (Cox *et al*., 2012). Texture, slope, altitude, and cropping season temperature were the factors with the next highest influence intensity. The values of these factors were relatively lower than that of organic carbon. Available macro nutrients (nitrogen, phosphorus, and potassium), age of the tree or orchard, growing degree days, wind speed during bloom period and cropping season rainfall were the next in influence intensity. A similar reason, namely coefficient of correlation values (association), holds good for influence intensity of other indicator parameters too (the influence intensity trend was pH, cation exchange capacity > microbial biomass, boron, calcium, variety > iron, zinc. These coefficient of correlation values are directly proportional to the role of each of these indicator parameters towards the $RPEI_a$, and consequently the yield. RPEI is primarily an indicator of overall production efficiency for predicting crop performance (Sharma *et al*., 2012).

On the basis of these indicator parameters and their influence intensity, the empirical model to evaluate the $RPEI_a$ (Equation 4: basic model) of almond was defined and used.

$$RPEI_a = \left(\sum_{i=1}^{n} W_i M \Big/ \sum_{i=1}^{n} W_i M_m\right) \times 100 \qquad \text{(Eq. 4)}$$

where

$RPEI_a$: Relative production efficiency index for almond;
W_i : Weight of indicator parameter;
M : Marks of the class in which the parameter or its value falls;
M_m : Maximum marks;
N : Number of indicator parameters;
I : Indicator parameter.

The $RPEI_a$ values were divided into various suitability classes (Sharma and Arora, 2010) on the basis of almond performance through a number of experiments.

For $RPEI_a$
> 80 : (C-I) Extremely suitable for almond cultivation;
70–80 : (C-II) Suitable;
60–70 : (C-III) Suitable with slight amendments;
50–60 : (C-IV) Less suitable;
< 50 : (C-V) Not suitable.

A model to estimate almond yields in California, including different variables, has been used earlier. The estimated yield results were generally consistent with expectations (Murua *et al*., 1993). Moreover, some successful projections related to the effects of climatic conditions on land suitability and production of almond have already been made using empirical models (Murua *et al*., 1993).

Land use planner for almond

The basic logic behind $RPEI_a$ was to plan economically beneficial land use for almond and to do so exhaustive analysis were done and another 'area' based empirical model (Equation 5) for planning land use for almond was also developed. For land use or almond orchard planting, 'area' also plays a significant role in relation to economic returns from the orchard. If area is smaller, higher value of $RPEI_a$ is needed.

$$S_a = (RPEI_a + A_r) - B \qquad \text{(Eq. 5)}$$

where S_a is Land suitability (economic) for almond and A_r is area in hectare and B is the base value of suitability class. If area ≤ 2 ha, the base value (B) of class C-I is considered; if area is > 2 and ≤ 10 ha the base value (B) of class C-II is considered and if area > 10 ha the base value of class C-III is considered.

If S_a is positive (+) the land is suitable for almond planting and if S_a is negative (-) or zero, the land is not suitable for almond planting. Suitability as per the above model should be considered only if the initial $RPEI_a \geq 60$. Earlier also a few empirical models to reflect agriculture environmental efficiency have been tried (Sharma *et al*., 2013) but a production efficiency based model for land use planning for almond crop has been developed for the first time. Prior empirical models (Jat *et al*., 2012) for land use change had never considered 'area' and '$RPEI_a$' together. Moreover, these models were developed for urban development. Some researchers had used an area-based model for projection of locations with safe chilling hours for some temperate fruit crops (Gary *et al*., 1998).

Sustainability yield index (SYI) and its relationship with $RPEI_a$

The SYI is a quantitative measure to assess sustainability of any agricultural or horticultural system or practice (Wanjari *et al*., 2004). The mean yield of each variety over the years, maximum yield attained by a variety in any year (maximum potential yield) and standard deviation were derived to identify an efficient variety for attaining a sustainable yield in the region. The estimates of SYI, mean yield, and $RPEI_a$ of each variety over the years (2011 onwards) are given in Table 3. Furthermore, relationship between SYI and $RPEI_a$ was also determined (Figure 3). A positive and significant relationship between SYI and $RPEI_a$ was observed. This is evident from the fact that higher values of the $RPEI_a$ means optimum status of soil, climatic, geographical, and crop parameters (Sharma *et al*., 2013) and thus lands with higher $RPEI_a$ had higher SYI. The linear regression equation, given below can be used for determining SYI based on $RPEI_a$:

$$SYI = 0.128 \times RPEI_a - 9.77$$

Sharma *et al.* developed and observed a positive and linear relationship of SYI with RPEI in maize crops in the foothill regions of the north-west Himalayas. High SYI with higher productivity was also reported by Jat *et al.* (2012).

Testing $RPEI_a$

To test the suitability and applicability of the basic model, average data of past few years (2011–2013) of some locations representing the almond-growing cold humid region of the northwest Himalayas were considered. The average values, of all the indicator parameters are presented in Table 4. The almond-growing areas are generally at a slope

Table 3. Evaluated relative production efficiency index ($RPEI_a$), nut yield, and sustainability yield index (SYI) of almond in the almond growing cold humid regions of the northwest Himalayas. VMR: Variation from mean $RPEI_a$.

Varieties	$RPEI_a$	Nut yield ($t\ ha^{-1}$)	SYI	VMR
'Pranyaz'	80.75	2.41	0.63	0.775
'Merced'	80.53	2.00	0.59	0.555
'Waris'	80.38	1.83	0.46	0.405
'Makhdoom'	80.23	1.55	0.54	0.255
'IXL'	80.00	1.54	0.45	0.025
'Shalimar'	79.63	1.38	0.39	-0.345
'Primorskij'	79.25	1.32	0.44	-0.725
'California Paper Shell'	79.03	1.14	0.38	-0.945

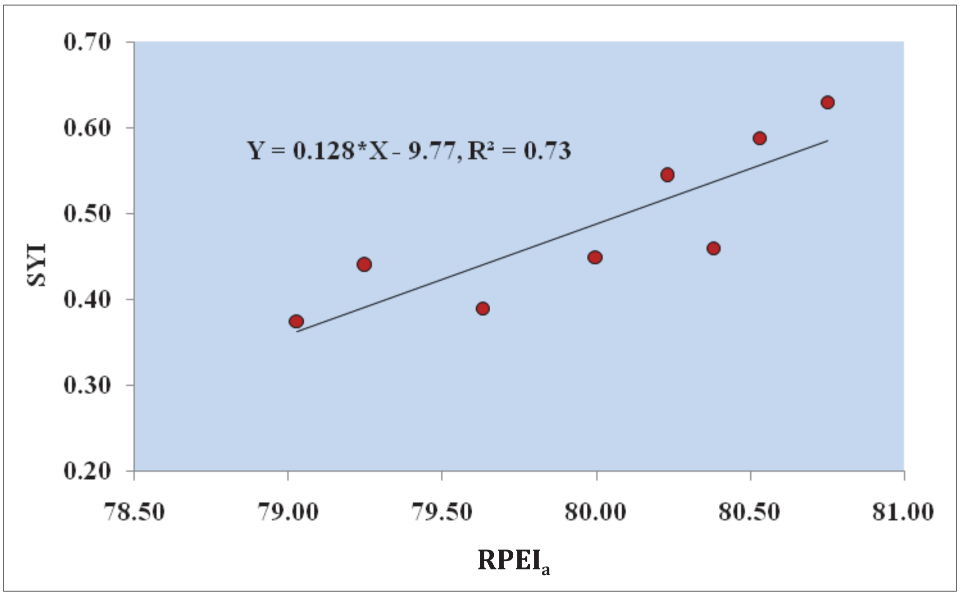

Figure 3. Relationship (positive and linear) between sustainability yield index (SYI) and relative production efficiency index ($RPEI_a$) in the cold humid regions of the northwest Himalayas.

of 0 to 2 degrees with an average altitude of 1,550 m a.s.l. The soils are generally sandy clay loam in texture with pH ranging from 6.6 to 7.7 and organic carbon ranging from 0.60 to 1.20. The soil-available N, P, and K contents ranged from 290 to 385, 18.0 to 29.0, and 250 to 320 kg ha^{-1}, with mean values of 355, 24.0, and 268 kg ha^{-1}, respectively. Calcium, boron, zinc and iron were in the range of 1.4–2.2 meq 100 g^{-1} soil, 0.51–0.70, 0.29–0.42 and 6.0–11.2 ppm, respectively. The cation exchange capacity of the soils in this region varied from 14.0 to 20.0 mol kg^{-1}. The average values of microbial biomass were around 347 µg g^{-1} soil. The cropping season rainfall, temperature, wind speed and accumulated GDD were 305 mm, 18.32 °C, 1.81 km h^{-1} and 1,726, respectively. The age of the trees was in the range of 8 to 12 years old.

Eight top varieties (improved) (CITH, 2012) grown in the area were considered for $RPEI_a$ evaluation. It was observed that 'Pranyaz' was having highest $RPEI_a$ value (80.75), followed by 'Merced' (80.53), 'Waris' (80.38), 'Makhdoom' (80.23), 'IXL' (80.00), 'Shalimar' (79.63) and 'Primorskij' (79.25). The least value of $RPEI_a$, 79.03, was noticed in variety 'California Paper Shell' (Table 3). Among the aforementioned varieties, the first five varieties were having $RPEI_a$ values falling in suitability class I, whereas the last three varieties were in suitability class II. Furthermore, the variety with higher values of $RPEI_a$ were having higher nut yield, *i.e.*, 'Pranyaz' which had the highest value of $RPEI_a$ had a nut yield of 2.41 t ha^{-1} followed by 'Merced' (2.00 t ha^{-1}), 'Waris' (1.83 t ha^{-1}), 'Makhdoom' (1.55 t ha^{-1}), IXL (1.55 t ha^{-1}), 'Shalimar' (1.38 t ha^{-1}), 'Primorskij' (1.32 t ha^{-1}), and 'California Paper Shell' (1.14 t ha^{-1}). Furthermore, to recommend best varieties for almond-growing cold humid regions of the northwest Himalayas, $RPEI_a$-based varietal supremacy among the improved varieties was evaluated (Table 3). The $RPEI_a$ values of 'Pranyaz', 'Merced', 'Waris', 'Makhdoom', and 'IXL' were more than the mean value, and they exceeded the mean by 0.78, 0.56, 0.41, 0.26, and 0.03, respectively. These varieties were considered superior amongst the improved varieties included in the study. According to Awasthi (2006), dominance of old traditional varieties is also one of the reasons for declining almond productivity in the region. For reducing the use of traditional varieties and promoting adoption of improved varieties, the performance of improved varieties was also analyzed. On comparing the nut yield of improved almond varieties during the past few years 'Pranyaz' exhibited the highest nut yield, followed by 'Merced', 'Waris', 'Makhdoom', 'IXL', 'Shalimar', 'Primorskij', and 'California Paper Shell'. This can be attributed to the corresponding $RPEI_a$ values. These values were evaluated using the empirical model developed to determine RPEI for almond. Among these improved varieties 'Pranyaz', 'Merced', 'Waris', 'Makhdoom', and 'IXL' were the best improved varieties and this again could be attributed to the positive variation in the $RPEI_a$ values of these varieties from the mean value.

TABLE 4. Observed average values of various indicator parameters to evaluate production efficiency of almond in cold humid region of northwest Himalayas. W_i: Weight of indicator parameter, M: Marks of the class in which the parameter or its value falls, M_m: Maximum marks; $RPEI_a$: Relative production efficiency index.

Parameters	Average values (3 years)	W_i	M	M_m	W_iM	W_iM_m	$RPEI_a$ [y]
Textural Class	Sandy Clay loam	0.07	0.3	0.4	0.021	0.028	
Slope (degree)	1 (0-2)[x]	0.07	0.4	0.4	0.028	0.028	
Altitude (m)	1,550.00 (1,500-1,760)	0.07	0.4	0.4	0.028	0.028	
Age of tree or orchard (year)	8.5 (8-12)	0.06	0.4	0.4	0.024	0.024	
pH	6.87 (6.6-7.7)	0.04	0.3	0.4	0.012	0.016	
OC (%)	0.72 (0.60-1.2)	0.08	0.3	0.4	0.024	0.032	
Av. N (kg ha^{-1})	355 (291-385)	0.06	0.2	0.4	0.012	0.024	
Av. P (kg ha^{-1})	24 (18-29)	0.06	0.3	0.4	0.018	0.024	
Av. K (kg ha^{-1})	268 (250-320)	0.06	0.3	0.4	0.018	0.024	
Ca (meq 100 g^{-1} soil)	1.87 (1.4-2.2)	0.03	0.2	0.4	0.006	0.012	
Boron (ppm)	0.61 (0.51-0.70)	0.03	0.2	0.4	0.006	0.012	
Zinc (ppm)	0.36 (0.29-0.42)	0.01	0.1	0.4	0.001	0.004	
Iron (ppm)	8.26 (6.0-11.2)	0.01	0.4	0.4	0.004	0.004	
CEC (C mol kg^{-1})	16.33 (14-20)	0.04	0.4	0.4	0.016	0.016	
Microbial biomass (µg g^{-1} soil)	347 (300-505)	0.03	0.4	0.4	0.012	0.012	
Cropping season rainfall (mm)	305 (290-330)	0.06	0.3	0.4	0.018	0.024	
Cropping season temperature (°C)	18.32 (17-20)	0.07	0.3	0.4	0.021	0.028	
Wind speed during bloom (km h^{-1})	1.81 (1.1-2.9)	0.06	0.4	0.4	0.024	0.024	
Accumulated GDD	1,726 (1,695-1,762)	0.06	0.3	0.4	0.018	0.024	
Varieties (traditional/improved*) *Traditional:* seedlings *Improved:* as listed	'Pranyaz'	0.03	0.40	0.4	0.0120	0.012	80.75
	'Merced'		0.37	0.4	0.0111	0.012	80.53
	'Waris'		0.35	0.4	0.0105	0.012	80.38
	'Makhdoom'		0.33	0.4	0.0099	0.012	80.23
	'IXL'		0.30	0.4	0.0090	0.012	80.00
	'Shalimar'		0.25	0.4	0.0075	0.012	79.63
	'Primorskij'		0.20	0.4	0.0060	0.012	79.25
	'California Paper Shell'		0.17	0.4	0.0051	0.012	79.03

* The eight best varieties of the region were considered.

[x] Values in brackets are the range values.

[y] $RPEI_a$ calculated using the following equation: $RPEI_a = (\sum_{i=1}^{n} W_i M / \sum_{i=1}^{n} W_i M_m) \times 100)$

Almond productivity and $RPEI_a$

Besides varietal variation and superiority, the $RPEI_a$ of almond-growing cold humid region was related to almond productivity (Figure 4). The trend of productivity was similar to that of $RPEI_a$. Data of six years reflected that the $RPEI_a$ value was highest during the year 2005–06 (83.93) and productivity was also the highest (9.27 q ha^{-1}) during the same year. Similarly, the lowest $RPEI_a$ value (74.68) was observed during 2007–08 and the corresponding productivity value (6.86 q ha^{-1}) was also the least during this year. A similar trend of crop productivity with RPEI has been previously observed (Sharma and Arora, 2010) in maize growing areas of north-west Himalayas. The overall almond productivity in cold humid region has declined in past six years. The peculiar geographic situations, non-scientific land-use planning and management (Kumar *et al.*, 2012), ignorance of production efficiency can be the main causes of this productivity decline.

Yield prediction model

After developing $RPEI_a$ and studying its relationship with almond productivity and SYI, an attempt was made to develop a production efficiency based yield prediction model too. Yield as well as RPEI for almond was analyzed statistically and a best-fit model, polynomial regression model, was developed. A significant relationship between almond yield and its corresponding $RPEI_a$ values was observed (Figure 5). On the basis of this relationship, an $RPEI_a$-based prediction model for nut yield was developed as follows:

$$\text{Nut yield (t ha}^{-1}) = 0.005 \times (RPEI_a)^2 - 0.645 \times RPEI_a + 21.37 \quad \text{(Eq. 6)}$$

This empirical model can be used to predict the almond yield on the basis of $RPEI_a$, which is further derived from 20 indicator parameters. Hence, this model is based on all those indicator parameters that were used to evaluate $RPEI_a$. A similar relationship between crop yield and RPEI has already been observed in northwest India (Awasthi, 2006). Similar empirical models were also developed by a few scientists (Gupta *et al.*, 2013; Alexander and Hoogenboom, 2000; Ramirez *et al.*, 2007). However, all these models were developed for other crops and were based on different parameters, for example the predictive yield model based on accumulated winter chill (Murua *et al.*, 1993). Empirical models once developed and validated, can be used to predict crop yield (Ramirez *et al.*, 2007).

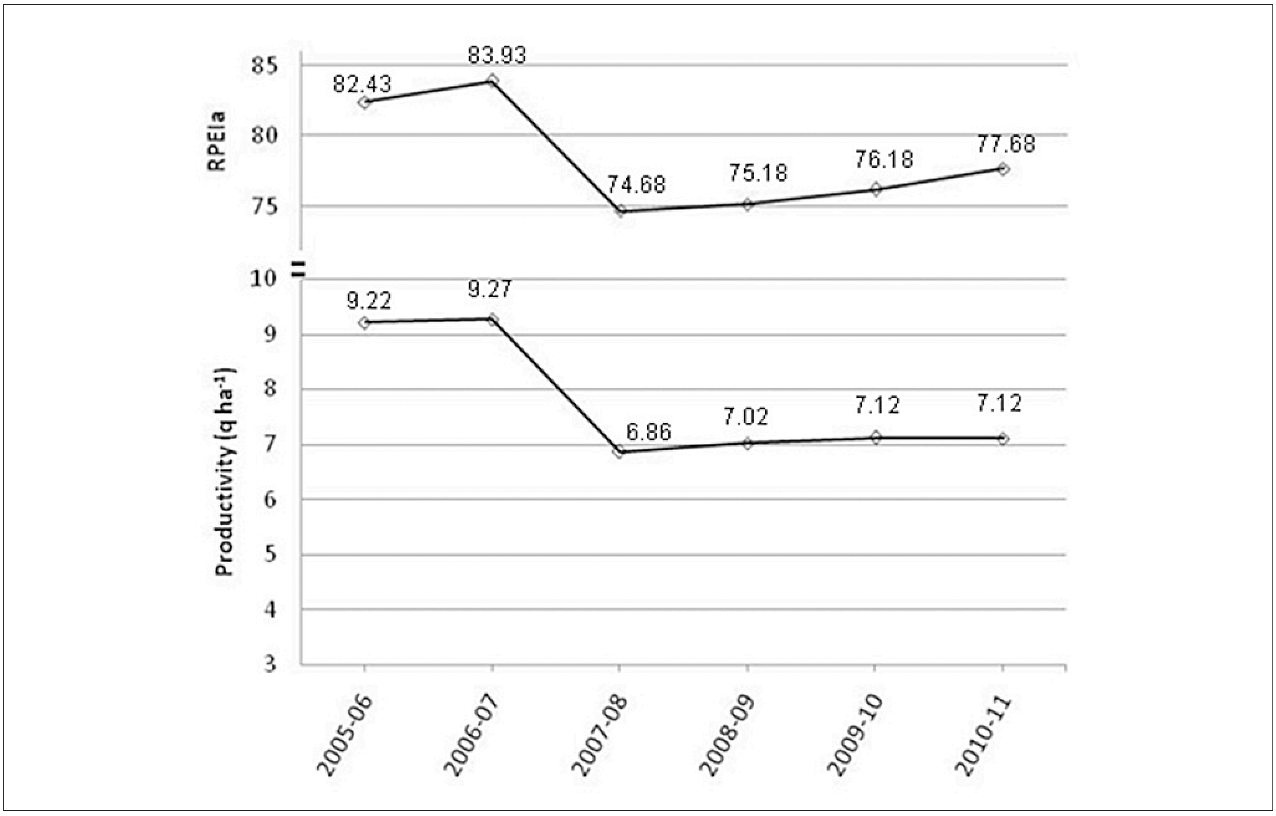

FIGURE 4. Six-year trend reflecting relationship between relative production efficiency index ($RPEI_a$) and productivity of almond in the cold humid regions representing the northwest Himalayas.

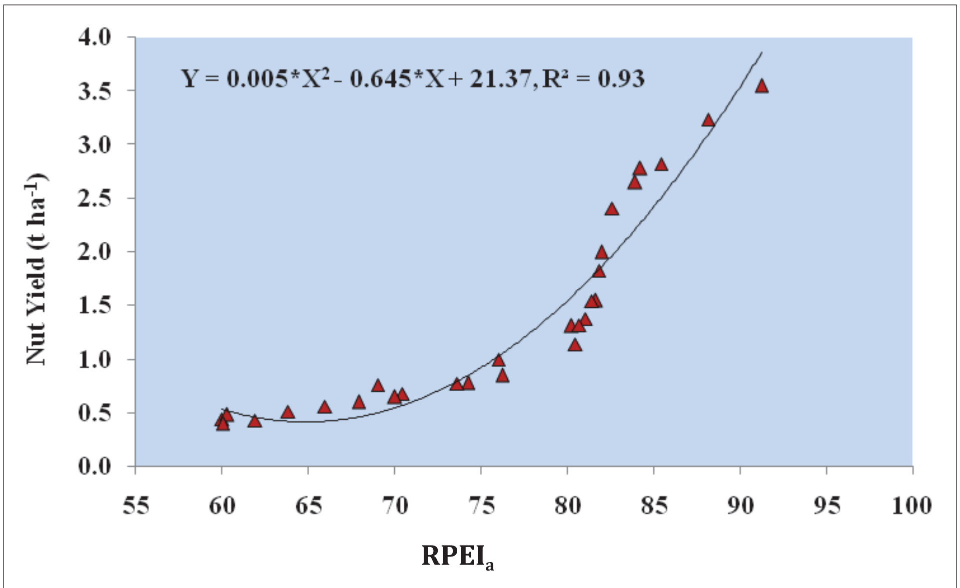

FIGURE 5. Almond yield as influenced by relative production efficiency index ($RPEI_a$) in the cold humid regions of the northwest Himalayas.

Conclusion

The methodology here developed to standardize indicator parameters for evaluating relative production efficiency index was reported for the first time. It can be used to standardize indicator parameters for any fruit crop. The $RPEI_a$ developed in this study will prove to be a crucial index that can be applied to land-use planning, yield prediction, and almond yield enhancement. The empirical findings suggest that the cold humid regions of the northwest Himalayas have the potential to increase almond production; however, this can be achieved only after planning correct and economically beneficial land use. The empirical models developed in this study will be crucial tools for managing global future yield demands of almond by enhancing the production and productivity of almond. The production potential and land suitability of newly developed almond varieties through breeding can be tested and recommended using the models developed in the present investigation. Furthermore, these models can be used for framing policies and creating contingency plans under different climatic and soil or location scenarios. These models will further prove to be highly effectual for land-use planning of almond cultivation in other regions. Nevertheless, almond farmers are unlikely to adopt this methodology directly because it requires some mathematical knowledge. However, they are likely to be attracted to the adoption of these methodologies, which can provide higher returns on the resources invested in terms of land-use planning and management. The farmers would be willing to use such technology or methods if they offer more attractive economic returns and fewer climate risks than existing methods do.

References

Alexander, V.A., and Hoogenboom, G. (2000) The impact of climate variability and change on crop yield in Bulgaria. Agric. For. Meteorol. *104*, 315–327. https://doi.org/10.1016/S0168-1923(00)00166-0.

CITH (2012). Annual Report (Srinagar, Jammu and Kashmir: Central Institute of Temperate Horticulture), p. 1–108.

Awasthi, R.P. (2006). Strategies for improving productivity of temperate fruit crops in India. In Temperate Horticulture: Current Scenario (Pitam Pura, New Delhi: NIPA), p. 193–200.

Bhattacharyya, R. (2011). Revealed comparative advantage and competitiveness: a case study for India in horticulture products (International Conference on Applied Economics – ICOAE).

Cochran, W.J., and Cox, G.M. (2000). Experimental Designs, 2nd ed. (New York, NY: John Wiley and Sons), p. 95–182.

Cox, J., Downie, A., Jenkins, A., Hickey, M., Kelly, R.L., McClintock, A., Powell, J., and Singh, B.P. (2012). Biochar in Horticulture: Prospects for the Use of Biochar in Australian Horticulture (NSW Trade and Investment).

Dominguez, S.G., Faz, A., and Zornoza, R. (2010). Characterization of almond orchards to assess soil fertility and organic matter dynamics to improve soil conditions by organic amendments (Brisbane, Australia: 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1–6 August), p. 39–42.

Dorfman, J., Dorfman, M., and Heien, D. (1988). Causes of almond yield variation. California Agric. p. 27–28.

Fleisher, D.H. (2002). Crop Models – Within controlled environment. Systems analysis and modelling in food and agriculture-crop models. Encyclopaedia of Life Support System (EOLSS).

Gary, C., Jones, J.W., and Tchamitchian, M. (1998). Crop modelling in horticulture: state of art. Sci. Hortic. *74*, 3–20. https://doi.org/10.1016/S0304-4238(98)00080-6.

Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., and Toulmin, C. (2010). Food Security: the challenge of feeding 9 billion people. Science *327*(5967), 812–818. https://doi.org/10.1126/science.1185383.

Grundy, C.A., and Turner, R.J. (2002). Horticultural weed control in organic systems – a modelling approach. (Aberystwyth, UK: Proceedings of COR Conference, 26–28 March) p. 295–298.

Gupta, N., Gill, K.K., and Ritu, B. (2013). Forecasting Ber yield and yield contributing characters – An agro meteorological approach. Int. J. Agric. Food Sci. Technol. *4*(5), 397–400.

Jat, R.A., Dungrani, R.A., Arvadia, M.K., Sahrawat, K.L., Ramirez, M.D.A., Diaz, E.A., Garcia, G.M., and Luna, R.G. (2012). Diversification of rice (*Oryza sativa* L.)-based cropping systems for higher productivity, resource-use efficiency and economic returns in south Gujarat, India. Arch. Agron. Soil Sci. *58*(4–6), 561–572. https://doi.org/10.1080/03650340.2010.533172.

Kumar, D., Ahmed, N., and Verma, M.K. (2012). Studies on high density planting in almond in Kashmir Valley. Indian J. Hortic. *69*(3), 328–332.

Lamp, B.M., Connell, J.H., Duncan, R.A., Viveros, M., and Polito, V.S. (2001). Almond flower development: floral initiation and organogenesis. J. Am. Soc. Hortic. Sci. *126*(6), 689–696.

Lentz, W. (1998). Model applications in horticulture: a review. Sci. Hortic. *74*, 151–174. https://doi.org/10.1016/S0304-4238(98)00085-5.

Marcelis, L.F.M., Heuvelink, E., and Goudriaan, J. (1998). Modelling biomass production and yield of horticultural crops: a review. Sci. Hortic. *74*, 83–111. https://doi.org/10.1016/S0304-4238(98)00083-1.

McPhee, M.J. (2009). Mathematical modelling in agricultural system: A case study of modelling fat deposition in beef cattle for research and industry. (Cairns, Australia: 18th World IMACS/MODSIM Congress, 13–17 July), p. 59–71.

Murua, J.R., Carman, H.F., and Alston, J.M. (1993). California leads Spain in almond production, exports to world. California Agric. *47*(6), 11–14.

Nyomora, A.M.S., and Brown, P.H. (1999). Rate and time of boron application increase almond productivity and tissue boron concentration. HortScience *34*(2), 242–245.

Pandit, R.A., and Sharma, S. (2015). Dwindling of almonds in Kashmir Valley: A case study of district Pulwama. Int. J. Educ. Res. and Technol. *6*(1), 109–120.

Ramirez, M.D.A., Diaz, E.A., Garcia, G.M., and Luna, R.G. (2007). An empirical model to predict yield of rainfed dry bean with multiyear data. Rev. Fitotec. Mex. *30*(3), 311–319.

Sharma, A., and Arora, S. (2010). Soil quality indices and relative production efficiency for maize and wheat crops in agroclimates of Northwest India. Soil Sci. *175*(1), 44–49. https://doi.org/10.1097/SS.0b013e3181cb478a.

Sharma, A., Arora, S., Jalali, V.K., Verma, V.S., and Singh, B. (2012). Non-exchangeable Potassium displacement in relation to Potassium availability to rainfed maize (*Zea mays*) under Nitrogen fertilization. Commun. Soil Sci. and Plant Anal. *43*, 2050–2061. https://doi.org/10.1080/00103624.2012.693236.

Sharma, A., Sankar, G.R.M., Arora, S., Gupta, V., Singh, B., Kumar, J., and Mishra, P.K. (2013). Analyzing rainfall effects for sustainable rainfed maize productivity in foothills of Northwest Himalayas. Field Crops Res. *145*, 96–105. https://doi.org/10.1016/j.fcr.2013.02.013.

Singh, R.P., Das, S.K., Bhaskara, R.U.M., and Reddy, N.M. (1990). Sustainable index under different management. Annual Report (Hyderabad, India: Central Research Institute for Dryland Agriculture).

Skirvin, D.J. (2011). Chasing the dream: A systems modelling approach to biological control. Acta Hortic. *916*, 129–140. https://doi.org/10.17660/ActaHortic.2011.916.13.

Srinavasarao, C.H., Venkateswarlu, B., Lal, R., Singh, A.K., Kundu, S., Vittal, K.P.R., Patel, J.J., and Patel, M.M. (2014). Long-term manuring and fertilizer effects on depletion of soil organic carbon stocks under Pearl millet-Cluster bean-Castor rotation in western India. Land Degr. and Developm. *25*, 173–183. https://doi.org/10.1002/ldr.1158.

Thapa, G.B., and Yila, O.M. (2012). Farmers land management practices and status of agricultural land in the Jos Plateau, Nigeria. Land Degr. and Developm. *23*, 263–277. https://doi.org/10.1002/ldr.1079.

Varmudy, V. (2011). Almonds: King of nuts in big demand. Facts for You, p. 18–20.

Wanjari, R.H., Singh, M.V., and Ghosh, P.K. (2004). Sustainable yield index: an approach to evaluate the sustainability of long term intensive cropping systems. J. Sust. Agric. *24*, 39–56. https://doi.org/10.1300/J064v24n04_05

Received: Apr. 20, 2017
Accepted: Jul. 7, 2017