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# Climate sensitive measure of agricultural intensity: Case of Nepal

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A B S T R A C T

While acknowledging the influence of climate on agricultural intensification, most studies have ignored its application in the measurement of intensity. Through the inclusion of climate variables, this paper develops a time-weighted measure, the Crop Potential Index (*CPI*), which can be used to assess the production potential of a region. The *CPI* is compared with the more conventional method, Cropping Intensity (*CI*), to assess the significance of their differences in the three ecological zones of Nepal. The comparison of the *CPI* with that of the *CI* shows a significant difference between the two measures in all three ecological regions. The level of difference is larger in regions where climate is a limiting factor, such as the Mountain region of Nepal. The climate sensitive *CPI* can be considered as a more complete measurement tool and can be useful for planning agricultural development activities in Nepal. The advantage of the *CPI* is apparent in its ability to set a theoretical upper limit to the production potential of crops in a specific climatic region. Compared to the *CI* the *CPI* is more realistic in quantifying agricultural intensity in regions where climatic factors set the theoretical upper limit for crop growth and development.



## Introduction

The spatial organization of agricultural intensity and patterns has long been an important area of inquiry in geography. Since the 1970s, geographers also have made a significant methodological contribution in the measurement of agricultural intensity. Yet, the methods used in calculating its index have ignored (or held constant) the significance of biophysical factors in determining the level of intensity. This is despite the fact that geographers such as Turner, Hanham, & Portararo (1977), Dayal (1978, 1984), Brookfield (1984, 2001), Shriar (2000) and many others have acknowledged the importance of biophysical factors (e.g., temperature, precipitation) as one of the determinants of intensification. Studies attempting to explain the process of agricultural intensification have generated, not surprisingly, partial and incomplete understanding of the index in a specific locale, particularly when it comes to understanding the agricultural production potential.

It is commonly understood that the process of intensification has also has been constrained by environmental factors, including available crop growing days, landforms and soil moisture (see Pingali, 1990; Matson, Parton, Poer & Swift, 1997; Giller, Beare, Lavelle, Izac, & Swift, 1997; Wood & Pardey, 1998; Pinstrup-Andersen & Pandya-Lorch, 1998; Brookfield, 2001; Fischer, van Velthuizen, Shah, & Nachtergaele, 2002, p. 154; Aune & Bationo, 2008; Linares, 2009). For example, the agricultural land in the higher latitudes has a shorter growing period due to lower temperature, and constraining land use activities during specific periods of the year. Humid lower latitudes, in contrast, have a longer growing period, allowing possibility for cultivation throughout the year (Shrikant & Chan, 2000; Jagtap & Chan, 2000). Likewise, cultivable land of the arid climatic regions is limited in the availability of soil moisture (Rao, Mayeux, & Dedrick, 2004, chap. 3, pp. 25–34). Provided other factors of production are held constant, arable land in tropical regions inherently has greater potential for land use intensity. That is why substantial knowledge of production potentials of different geographic regions is required to assess how and where the enhancement of production through intensity can be achieved. As the need to improve agricultural intensity grows to meet the growing demand of population, it will be necessary to understand crop production potential of given agricultural land.

This paper proposes a new climate sensitive measure of agricultural intensity; a Crop Potential Index (*CPI*), which provides a standardized model for the characterization of climate and the length of the crop growing period. It provides an index of agronomically attainable intensity, necessary for understanding the production potential of basic land resource units. By making it a more climate sensitive measure, this paper addresses the shortcomings of existing methods of measuring agricultural intensity. Departing from conventional measures, this proposed method sets out to widen the context of intensification debate to the next level.

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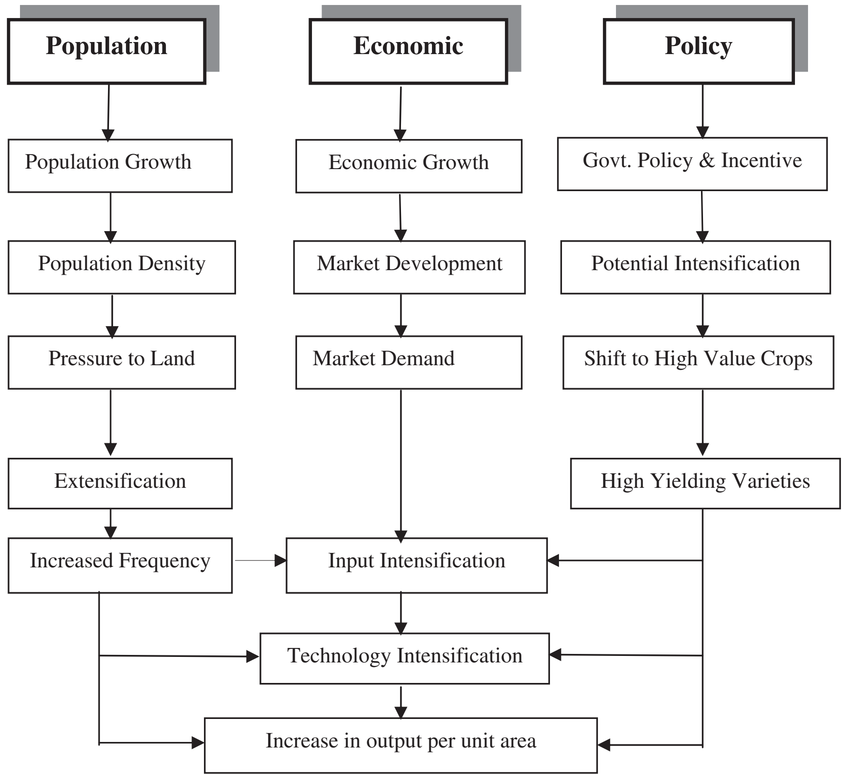


**Fig. 1.** Intensification pathways: a conceptual framework.

In the next section, a summary of the conceptual underpinnings of agricultural intensification is provided. Section three contains a review of existing methods used to measure the cropping intensity (*CI*). This section also provides the limitations of the existing methods as a measure of agricultural intensity. Section four introduces an agro-ecological perspective that illustrates the value of climate in the measurement of intensity, followed by an introduction of the new measure of the *CPI*. In the fifth section, an argument is made for *CPI* as a measure with potential to calculate agronomically attainable crop yields necessary for understanding production potential for basic land resources in question. A description of the data and its sources is provided in section six, followed by a discussion of the methods and the results of the analysis. The final section contains a summary of the overall findings of the new index of the *CPI*.

## Agricultural intensification

Following Boserup (1965, p. 144, 1981, p. 137) agricultural intensification has been defined as the movement from slash and burn system of agriculture to an annual cropping system whereby a plot of land is cultivated more frequently. It is seen as one of the indicators of the agro-ecological system's ability to respond to change, leading to some subtle but significant differences in its definitions. According to Boserup, agricultural intensification is driven primarily by the pressure of population growth. Although it is considered unilinear and reductionist in nature (Brookfield, 2001), Boserup's model has become the standard since the early 1980s as anthropologists, geographers and others quickly adopted it to explain agricultural intensification over space and time.

Brookfield (1972, 2001) and others have defined agricultural intensification as the substitution of inputs of capital, labor and skills for land to maximize production from land under cultivation. By this definition, it is measured in terms of output per unit of land or, as a surrogate use of inputs to crop production against constant land (Turner & Doolittle, 1978). One can distinguish between input intensification, as measured by the amount and types of input applied by the farmers, and output intensification, as measured in terms of output per unit of land. Lele and Stone (1989) viewed intensification somewhat differently in that they considered output as well as changes in the length of the fallow period. Kates, Hyden, & Turner (1993) suggested the use of agro-technologies as a measure of intensification. Dorsey (1999) applied the concept of intensification quite differently, using the degree of crop diversification and level of commercialization by the small farmers in Central Kenya as the indicators of intensification.

Although definitions have varied, the underlying logic of all the concepts discussed in the preceding paragraphs is to explain the process of intensification, and to provide a rationale for the increase in output per unit area. The challenge for measuring agricultural intensity is to account for, within an acceptable framework, the socio-economic determinants of agricultural land use as well as the spatial heterogeneity of the land's suitability for agricultural production, which is largely determined by environmental conditions. As illustrated in Fig. 1, intensity pathways can be analyzed using three separate perspectives driven by a) market, b) population and c) agricultural policy.

### *Market driven*

From the perspective of markets, economic incentive provided by the market is viewed as the main driver of agricultural intensification. Market driven approaches were originally explained through von Thunen's land rent theory, which postulates that optimal crop production allocation is determined by distances from the market (Sinclair, 1968; Bradford & Kent, 1987, pp 180; Grigg, 1995, p. 244). In this case, intensity is usually measured in terms of output per unit of land (Turner & Doolittle, 1978). It also has been linked with the hypothesis of induced innovation articulated by Hayami and Ruttan (1985, p. 367). Innovation, in parts, also is induced by market forces that seek more qualitative changes in the production system, leading to specialization or enhancement of skills. Induced innovation is a concept that also stresses change in the quality of inputs, with similar or greater expectation in production (Hayami & Ruttan, 1985, p. 367; Turner & Ali, 1996; Pender, 1998). This may be in the form of specialized inputs, change in the art of production, or even change in resource organization. In fact, market-induced intensity can be visualized as a continuum. At one end, changes occur through the improvement of existing technologies; at the other end, new and more productive technologies are developed to meet emerging demands.

*Population driven*

In this case, population acts as a powerful stimulus to the process of agricultural intensification. Much of the understanding of the concept of population driven intensification is rooted in Ester Boserup's (1965, p. 144) work. Although faulted for its reductionist approach, this perspective has been a powerful stimulus for researchers working with agricultural change beyond the field of economics. The model outlines a general sequence of reactions to population growth. The initial response is the expansion of area under cultivation followed by a shortening of the fallow period and subsequent progress toward multiple cropping. Intensity, as defined by this perspective, includes neither the level of inputs used nor the methods of cultivation, but it does imply that a higher frequency of cultivation requires a higher input of labor and possibly other inputs (Salehi-Isfahani, 1993; Dayal, 1997, pp 229). Researchers have widely applied frequency of cultivation as a surrogate measure of agricultural intensification. Although this concept of measuring agricultural intensity has been thoroughly reviewed and criticized (e.g., Brookfield, 1972, 1984, 2001; Brown & Podolefsky, 1976; Doolittle, 1984), it is still considered to be a simple and widely prevalent measure. Its use of land use data also makes it "more reliable and available for longer spans of time" (Dayal, 1997: pp. 115,229). However, despite widespread application of this concept in the study of intensification, it has its limitations; it does not take into account climate conditions, cropping techniques or productivity of land, affect agricultural intensity (Turner et al., 1977). These are discussed in greater details in the later part of this paper.

*Policy driven*

A third and nascent concept is the policy dimension, which argues that intensification is a function of policy adopted by an individual country for its agricultural development (Lele and Stone, 1989). In most countries, governments have played a central role in dictating agricultural policies (through subsidies, loans, agricultural extension, research and development of technologies, access to market), and the processes of intensification have gained momentum when they are couched within policy that fosters them. Binswanger and Pingali (1988) paid greater attention to the policy issue for intensification by distinguishing it from other concepts. This argument has been further reinforced by Hayami and Ruttan (1985, p. 367) with the development of the concept of induced institutional innovation, and later by Lele and Stone (1989), who elaborated the role of policy in their study of selected countries of Africa. The policy driven concept of intensification revolves around three major areas: (a) development of more productive activities on high potential land; (b) policies to innovate high yielding crop varieties; and (c) promotion of high value crops. This concept, however, is still evolving and remains to be quantified. The following section illustrates major methods of quantifying; it discusses the existing methods of calculating cropping intensity and also their shortcomings.

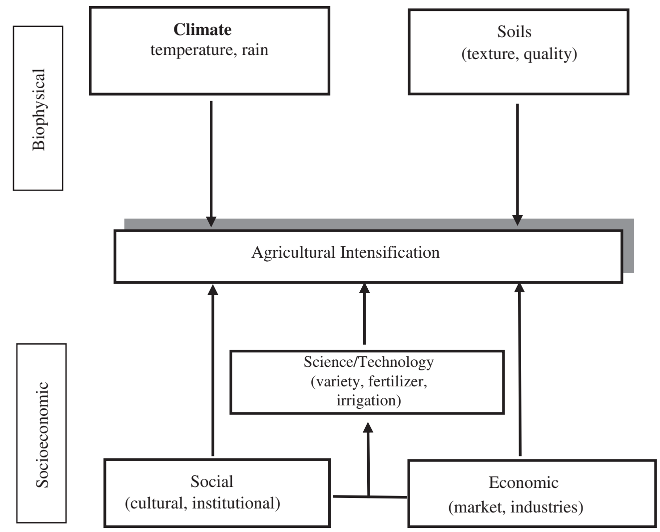


**Fig. 2.** Driving forces affecting agricultural intensification.

## Current measures of intensification and their limitations

Among the most prevalent method used in calculating the cropping intensity index is the *CI*. It is calculated using the land use data, especially the frequency of cropping (Kates et al., 1993; Das & Das, 1994; Yadav, 1994; Dayal, 1997, p. 229). In this case, the *CI* is defined as the ratio of net cropped area to the total hectares of arable land. The total cropped area is quantified by measuring the area of each crop sown (i.e., double-cropped area is counted twice), and can be represented by:

$$CI = \frac{Ha_c}{Ha_T} \tag{1}$$

where, $Ha_c$ is the sum of hectare(s) cropped in a year; and $Ha_T$ is the total arable land.

As discussed earlier, *CI* does not include levels of inputs used or management skills applied in crop cultivation, but it does imply that a higher frequency of cultivation will require higher degrees of inputs and management skills (Dayal, 1997, p. 229). Furthermore, the gross cropped area is derived in an unsatisfactory manner, since the emphasis is on the frequency of cropping and ignoring the actual land use (Dayal, 1978). For example, a hectare of land used for three short duration crops grown sequentially may occupy nine to twelve months and be counted as 3 ha (higher intensity). On the other hand, a hectare of land remaining under one crop for a whole year, such as sugarcane or tobacco, is considered as 1 ha only (low intensity) despite the fact that the crop in the later case occupied land longer, and thereby misrepresents the intensity patterns.

Dayal (1978), by incorporating the effect of the duration of the crop in the field, proposed a time-dependent method to calculate *CI*. He suggested that the *CI* be the "ratio of the aggregate of crop areas under various crops, each weighted by the duration of the crop in the field, to the net sown area – actual area used for cropping in any one year (Dayal, 1978: 290)". This time-dependent method is specified by the equation:

$$I_c = \frac{\sum_{i=1}^{n} A_{ci} \cdot d_i}{Q}, \tag{2}$$

where $I_c$ is the cropping intensity index, $A_{ci}$ is the area under crop *i*,

$d_i$ is the duration of crop $i$ in the field, and $Q$ is the net sown area in the a real unit concerned (arable land).

While being sensitive to crop duration, as represented by the fraction of total hectare months, Dayal's method is limited to crop duration determined by crop types. It fails to include the crop production potential of given agricultural land as determined by climate. For example, sugarcane is, by type, a longer duration crop than either maize or paddy. While this aspect is incorporated in the above measures, what is not considered is the influence of temperature on the growing period in determining the duration of each of these crops. Such oversight can be more apparent in a region with different ecological zones, where the crop maturity period for a crop (e.g., maize) ranges from three to six months, or even longer depending on its climatic location.

The challenge to intensity measurement is that it is influenced by the interaction of several factors (see Fig. 2), including characteristics of climates, soils, and social, economic, and technological development (Mannion, 1995; Shriar, 2000). These factors vary both spatially and temporally and account for the high spatial variation in intensity of agricultural land use. Climate, the single most important factor in determining the geography of agriculture intensification (Rice & Vandermeer, 1990), is not made explicit in most measurement methods. The importance of climate lies in the fact that it determines the potential for agricultural intensification (Brklacich, McNabb, Bryant, & Dumanski, 1997; Pingali, Hossain, & Gerpacio, 1997, p. 331)

While the length for crop maturity is determined also by its genetic make-up, variations in climatic conditions may shorten or lengthen a crop's growth phases or cycles, such as germination, bud-setting, blooming, fertilization, fruiting and maturity (Tivy, 1990, p. 288). The growing period, on the other hand, is determined solely by climatic factors (Kassam, Shah, van Velthuizen, & Fischer, 1990), especially temperature. Therefore, it is essential to consider the length of the frost-free growing period, as determined by the climate of a site, in order to know the true potential of productivity and crop geography. When land is suitable for cultivation, it is understood as being available for cropping. For example, the length of crop the growing period in warm humid tropics can range from 270 to 365 days, while this may extend from 75 to 180 days in cool temperate areas (Pingali et al., 1997, p. 331; Shivakumar & Valentin, 1997, Shivakumar, Gommes, & Baier, 2000). In cold climates, crop maturity is subjected to a longer duration and a shorter growing period, implying that there is limited time available for a limited number of crops per year (FAO, 1980, 1982).

The major deficiency in the existing methods of measuring agricultural intensity is that they do not take into account temperature's influence on crop duration and the growing period. Intensity measurements that are not able to incorporate this dimension cannot be a useful tool for policy and management purposes as they misrepresent the spatial patterns of intensity. It is within this premise that I argue that current methods of computing intensity indexes are not climate sensitive, and apply a "one size fits all" definition to different agroclimatic regions. Although existing methods have contributed substantially toward the understanding of the level of agricultural productivity, they have shed little light in explaining regional variations of agricultural productivity brought about by climatic differences; hence, they are imperfect in the measurement of agricultural intensity. This rigidity with respect to climate variables implies that current methods of intensity measurement are unable to represent the actual potential of the productivity of land. While this might not be an issue in a region or country with a homogeneous environment, it is a problem in places with diverse agroclimatic conditions. In addition, the *CI* fails to take into account a crop's climatic requirements for growth and maturity. This misconception is compounded by the assumption that arable land is a constant unit and is available for cultivation throughout the year in every climatic condition. No attention is paid to how long the land is *not* suitable for cultivation due to climatic constraints. For example, land in temperate climates, with a growing period of only six months, remains unsuitable for cultivation for half the year. If intensity is calculated on the assumption that arable land is available for cultivation all twelve months, as is conventionally done, the value of intensity obtained, without the adjustment for the crop growing period, is actually misleading. By contrast, land in warm tropical areas is available for cultivation throughout the year. With a longer growing season, land can be cultivated for all twelve months. While in the latter case, the existing intensity index is fairly representative; in the former; it becomes deflated because the denominator value of arable land is large due to the assumption that it is available to cultivation for all twelve months. Therefore, applying a single method as the standard to calculate intensity over a wide range of climatic conditions misrepresents the actual intensity pattern. This paper argues that if intensity measures are to be used as a tool for planning agriculture development, they should incorporate biophysical factors that determine the "agronomic threshold" of intensity of land use.

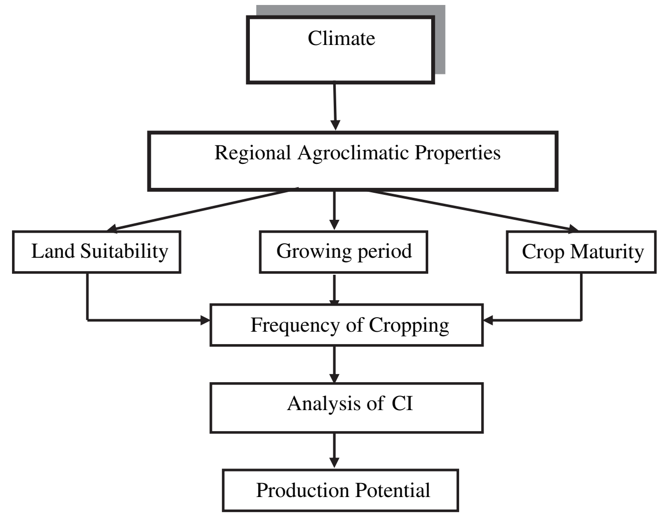


**Fig. 3.** Assessing agricultural intensification: an agroclimatic perspective.

## Agro-ecological perspectives and cropping intensity

The sequences of crops grown during a year are determined by the interaction of climate and management parameters (FAO, 1982; Kassam et al., 1990; Fischer et al., 2002, p. 154). Environmental constraints on arable land, particularly climate, determine the geography of agricultural land use and, thus, potential for crop production. Based on this close relationship between climate and agriculture, researchers have developed the concept of *agro-ecological zones methodology*, or AEZ. As illustrated in Fig. 3, the AEZ an approach that classifies cultivable land based on common characteristics of climate, soil, and landform within a region (see FAO, 1982; Fischer et al., 2002, p. 154).

In 1976, the Food and Agricultural Organization (FAO) began the Agro-ecological Zones Project (AEZ) to assess the production potential of land resources in 117 developing countries. This project developed national inventories of land resources and provided assessments of land suitability for agricultural production. The project also provided agricultural research at national, regional and local levels (FAO, 1982; Kassam et al., 1990). Over the past 30 years, the AEZ has become widely used to assess specific land management conditions, determine the level of inputs, and quantify production potential in the specific agro-ecological context (see Jagtap & Chan, 2000; Karing, Lallis, & Tooming, 1999; Shivakumar & Valentin, 1997; Pingali et al., 1997, p. 331; Kassam et al., 1990). Using the concept of AEZ, in 1992, the Consultative Group on International Agricultural Research subdivided the major agroclimatic regions of the developing countries into nine AEZs. The availability of digital global databases of climatic parameters, topography, soil and terrain, and land cover have allowed further improvements in the use of AEZ methodology. The FAO in collaboration with International Institute for Applied Systems Analysis (IIASA) further refined AEZ methodology and spatial land resources database to assess production potential of major food and fiber crops, under various levels of inputs and management conditions (Fischer et al., 2002, p. 154). By making use of digital geographical databases, this new method expanded the specific characteristics of seasonal temperatures and other climatic parameters to assess crop suitability and land productivity potentials in various climatic regions of the world.

The current AEZ methodology is based on variable global quality. For example, the world soil map is based on a 1:5,000,000 scale map, and its reliability varies considerably among different areas (Fischer et al., 2002, p. 154). Likewise, the resolution climate data are also coarse and derived from a half-degree latitude/longitude world climate data set. Another related issue is that the current land degradation is hard to quantify accurately using the available data set at the global level. Also, the agronomic data, such as those on environmental requirements for some crops, contain generalizations necessary for global applications. Since the AEZ methodology commensurate with the resolution of the basic data, the results obtained from this source should be treated cautiously.

## Toward a new method for computing cropping intensity

The new method of computing cropping intensity incorporates the effect of crop duration in the field and the length of the available growing period. It is an improvement of Dayal's method of computing the intensity index in that it is adjustable to different climatic settings. This intensity measure provides the potential intensity index and is the ratio of the aggregate of crop areas under various crops, each weighted by the duration of the crop(s) in the field to the net cultivated area adjusted to the length of the frost-free growing period. This procedure is specified by the following equation:

$$CPI_j = \frac{\sum_{i=1}^{n} (DC_i \cdot Ha_i)}{(Ha_T \cdot GS)} \tag{3}$$

where $CPI_j$ *is* Crop Potential Index for region *j*, $DC_i$ is duration of crop *i* per year (including double cropping and single crops overlapping two growing period), $Ha_i$ is hectares planted to crop *i*, $Ha_T$ is total arable hectares, *GS* is number of months of the frost-free growing period and *n* is number of crops planted annually.

This *CPI* gives crop months per hectare of net cultivated area adjusted to the available frost-free growing period, which is more satisfactory than the one proposed by Dayal (1997, p. 229). In addition, this measure reveals those areas within the given region (s) where intensity can be improved by increasing the frequency of cropping because the index shows the average number of available months a hectare of crop land is under cultivation. The *CPI* is different from the conventionally derived *CI* in that it provides the potential upper limit for increasing cropping intensity through multiple cropping, which is not the case with *CI*. The maximum potential index of this measure is never more than one. An intensity index that is close to one is an indication that the region has been subjected to the upper limit of multiple cropping. Further increase in production in such a region entails other improvements, such as change in technology, inputs and management options.

To demonstrate the difference in the intensity index due to methods of measurement, this paper uses Nepal as a case. In doing so, the paper also offers an alternative method of measuring cropping intensity that is sensitive to climate. The new index will facilitate the understanding of the crop production potential by means of multiple cropping. Since the new index, the *CPI*, is a time-weighted measure, it gives feedback on the remaining time available for cultivation of a second crop.

## Data and their sources

As has been discussed, this paper postulates that a climate sensitive measure of agricultural intensity converges into a theoretical upper limit on the production potential of a region. In the previous section, I proposed the use of *CPI* to be such a measure. This section is devoted to a more detailed discussion of the research materials required to calculate the *CPI* as well as a brief description of the data sources.

The units of observation used to illustrate the case are the districts of Nepal, an agro-climatically diverse country nestled in the Himalayas and sandwiched between India and China. There are a total of 75 districts (local civil and administrative divisions) in the country with 16 in the Mountain region, 39 in the Hills and 20 in the Terai or the plain region. While the study of all 75 districts would have been preferable, inadequate climate information limits this effort to 32 districts (Mountain = 7; Hills = 15; and the Terai = 10) accounting for 46 percent of the total arable land of the country.

Most of the meteorological stations are distributed in areas of agricultural and economic significance. They usually are found in districts with regional headquarters, airports and agricultural research stations. The meteorological stations in the Mountain and the Hills are located in the valleys, mid-hills and high hills encompassing the major climatic aspects of each region. In the Mountain region, for example, the meteorological station in Chainpur (Sankuwasabha district) is located in the lower elevation (1329 m) and the Namchebazar (Solukhumbu) station is located in the higher elevation (3450 m), capturing a range of crop growing areas of the Mountain region. Similarly, in the Hills, the meteorological station in Dipayal (Doti district) is located in the valley bottom (617 m) and the Dadeldhura station (Dadeldhura district) is located at a higher elevation (1865 m), representing the wide range of crop growing areas of the Hills. Relatively homogenous climate of the flat Terai region is represented by the meteorological stations located at regular intervals in this belt. The only area that is relatively under-represented is the northwestern part of the Mountain region. This area is quite remote, inaccessible and sparsely populated, and livestock herding is the main form of agricultural practice. The record of temperature data from the meteorological stations for each ecological zone is used to derive the growing period length for districts in question. For each selected district, the Nepalese agricultural land use data for five major cereal crops (rice, maize, wheat, millet and barley) is used to calculate cropping intensity. The selection of these five cereal crops is based on the land acreage covered by these crops. According to NPC/UNICEF (1996, p. 79), these cereals occupy more than 80 percent of the total arable land nationwide and, therefore, adequately represent the cropping patterns of Nepal. Agricultural land use data from the period between 1983/84 to 1991/92 has been averaged. By averaging the land use data, this paper also embeds temporal variations. These data have then been used to compute both the *CPI* and the *CI*.

This study uses the district (local civil divisions) agricultural land use and climate (temperature) data from the Statistical Year

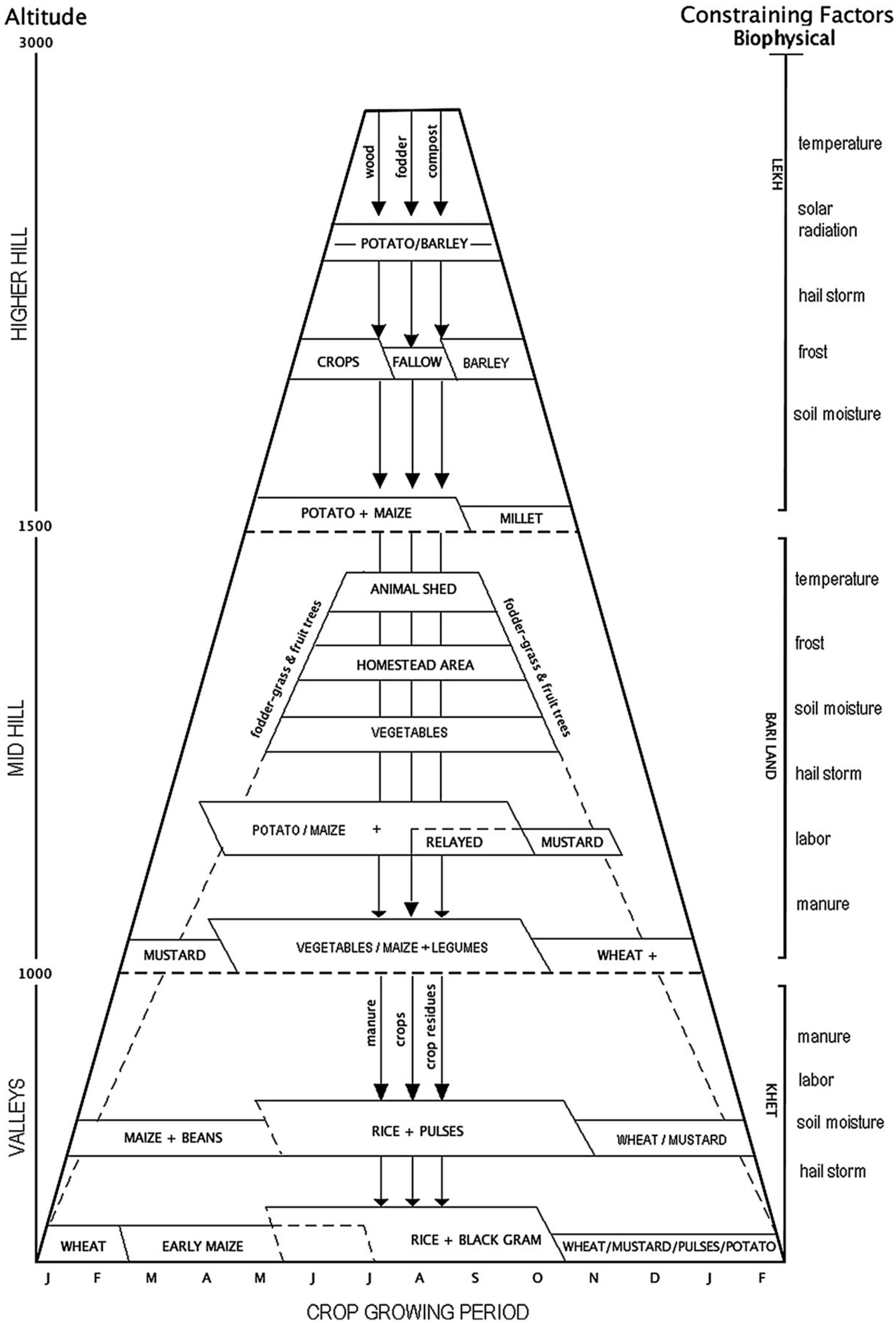


**Fig. 4.** Schematic representation of cropping patterns as determined by altitude in Nepal. *Source*: Sthapit, 1983.

Book of Nepal 1995 (HMG/NPC/CBS-Nepal, 1995). The crop duration for each ecological region is derived from the crop calendar reported by Cropping Systems Research Program of the Government of Nepal (Malla et al., 1980), and has been verified by using the crop calendar published by Shrestha (1989) in the International Center for Integrated Mountain Development (ICIMOD), the premier multi-governmental mountain research organization in Nepal. Shrestha's calendar represents the eastern part of Nepal and is inclusive of all three ecological zones of that area. Data pertaining to land use and climate were verified through other governmental documents (HMG/NPC/CBS-Nepal, 1991/92; HMG/NPC/CBS-Nepal, 1993; HMG/NPC/CBS-Nepal, 1994; HMG/NPC/CBS-Nepal, 1998).

Both measures, the *CI* and the *CPI*, require land use data, i.e., i) hectares planted to crop(s), and ii) total arable hectares. The hectare planted to crop is defined as the area planted by a crop in a given year and is computed by summing the area occupied by five major cereals annually. This generates the hectares planted to crop for each district. Both land use variables are averaged over time (i.e., there is only one value per district). The total arable hectare refers to all land under cultivation. In Nepal, land used for annual cropping, temporary fallow and meadows is considered arable. The area under arable land for all districts was obtained from the census of 1991/92.

In addition, the *CPI* also requires climate variables: i) duration of crop per year, and ii) number of months of frost-free growing period. Fig. 4 illustrates the cropping patterns as influenced by the altitude. As illustrated, farmers in the lower altitude can grow as many as three crops a year per plot, provided there is no constraints in soil moisture. However, this is not the case in the higher altitudes. In other words, the food production potential is higher in the lower altitude (Terai) region than in the higher altitudes (Hills and Mountain). In much the same way, the number of months of the frost-free growing period is also affected by the altitude. It can range from as many as twelve months in the Terai to as little as six months in the Mountain region. So the Terai, with a longer growing period and shorter crop duration, has a higher potential for food production through multiple cropping. This is not the case in the Hills and the Mountain region, where the crop growing period is shorter and it also takes a longer time for crops to mature. Thus, the measurement of agricultural intensity needs to incorporate climatic variables to generate a more realistic intensity measure. The *CPI* has the ability to distinguish these differences.

While crop duration is one of the agronomic traits, its growth phases or cycles are influenced by climate. To determine the crop duration for the Terai region, the crop calendars from two Cropping Systems Research Sites (Chitwan and Parsa districts) have been used. For the Hills, the crop duration is determined by averaging information from three research sites (Lalitpur, Kaski, and Rukum disticts). The Lalitpur site is located in the high hills, Kaski in mid-hills and the Rukum site is located in the valley bottom. In addition, a crop calendars developed by Sthapit (1983) for the Hills of western region of Nepal were used to derive the crop duration for the Hills. The Mountain belt is characterized by a longer crop duration than the Terai and the Hills. For the purpose of calculating crop duration in the Mountain, the crop calendar from a cropping systems research site (Sankhuwasabha district), along with the calendar developed by Shrestha (1989) have been used.

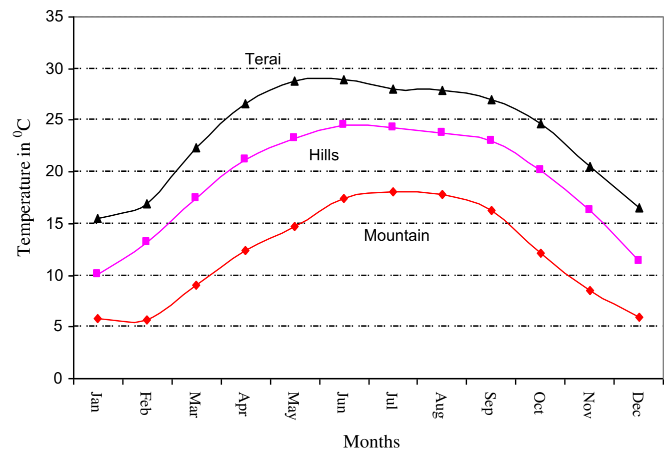


**Fig. 5.** Mean monthly temperature for the three ecological regions of Nepal.

The length of the frost-free growing period, defined as the average length of period without frost (Monteith & Scott, 1982), also determines the geography of agriculture. Although the concept of the frost-free growing period is widely used in modeling crop yield, especially in developed countries, its application in the measure of crop intensity is disregarded. I argue that arable land should be considered arable only when there are conditions conducive for cultivation of crops. This can be achieved only when the intensity measure includes the frost-free growing period to determine the suitability of arable land for crop cultivation.

The concept of the growing period can be climatic and thermal (e.g., Bayliss-Smith, 1982, p. 112; Tivy, 1990, p. 288). For the purpose of this thesis, the thermal or the frost-free growing period has been adopted because of its focus on temperature. The frost-free growing period can be computed from daily minimum temperatures and also from monthly mean temperatures (Neild & Seeley, 1977). Daily minimum temperatures would be a more precise measure of obtaining the frost-free growing period. However, due to

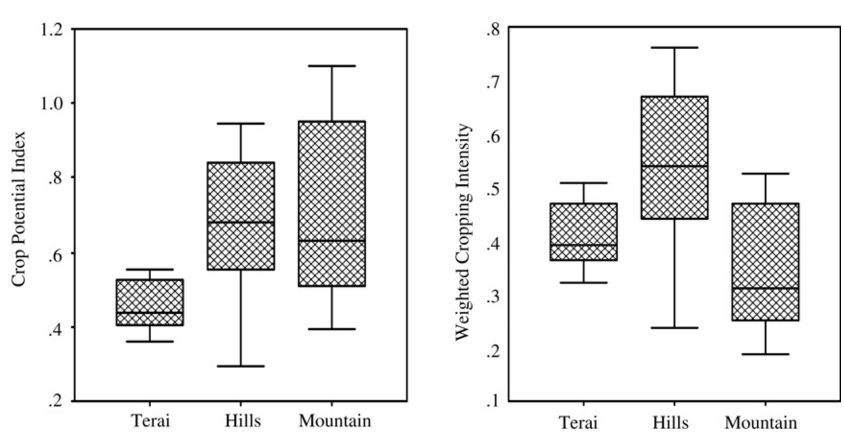


**Fig. 6.** Boxplots of the *CPI* and the *CI*.

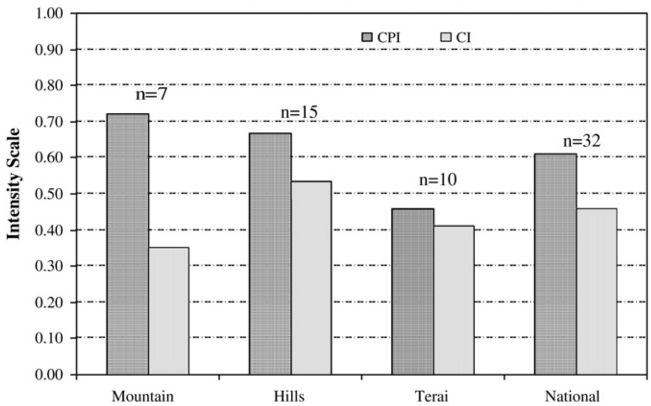


**Fig. 7.** Means of the *CPI* and *CI* at Regional and National Levels of Aggregation.

unavailability of daily temperature data from the climate stations of Nepal, the average monthly mean temperatures have been taken as the basis for determining the frost-free growing period. The mean monthly temperature is computed by averaging the monthly maximum and minimum temperature for a period of up to ten years, wherever such data existed. Based on this, the interval of months with a mean temperature below 6 °C is designated as being frost-prone and unsuitable for arable farming. For example, if a district has three months with temperatures below 6 °C, then their arable hectare month is nine. The total amount of arable hectare land is adjusted according to frost-free months. Fig. 5 presents the mean monthly temperatures based on the meteorological records of the sample districts.

## Methods and the analysis of results

It should be noted here that the *CPI* places a theoretical upper bound on the index of cropping intensity, while no such upper limit exists with the *CI*. In theoretical terms, the maximum potential value of the *CPI* is one. So the intensity index close to one indicates that the region has been subjected to maximum cropping intensity. The *CI* simply provides an index of land use based on the ratio of net crop area to total hectare of arable land, and is unable to provide feedback on the potential for increasing intensity by means of multiple cropping.

To test this difference, average values of cropping intensity derived by both the *CPI* and the *CI* are compared in each of the three ecological regions using one-way analysis of variance (ANOVA). The intensity of agricultural land use as measured by both the *CPI* and the *CI* are the dependent variables and the three ecological regions to be compared are the factors or independent variables. In addition, mean differences in cropping intensity between the *CPI* and the *CI* is compared in a paired-comparison *t*-test, a commonly used method to evaluate the differences in means between two groups. It is calculated as:

**Table 1**
Results of ANOVA, between ecological regions for the *CPI*.

| Source | *n* | *df* | *SS* | *MS* | *F*-Ratio |
|---|---|---|---|---|---|
| Between group | 3 | 2 | 0.361 | 0.180 | 4.574** |
| Within group | 32 | 29 | 1.144 | 0.039 | |
| Total | 32 | 31 | 1.505 | | |

*Note*: $n$ = number, $df$ = degree of freedom, $SS$ = sum of square and $MS$ = mean square.
**Indicates significance at 0.01 level as computed by Scheffe *post hoc* analysis.

$$t = \frac{\text{average of difference}}{\text{SD}/\sqrt{n}}$$

where *SD* is the standard deviation and $n$ is the number of observations.

As shown in Fig. 6, the horizontal line in the middle of the box marks the median, and splits the box into approximately equal halves. In the Hills, the median of both the *CPI* and the *CI* is almost symmetric with similar overall spread characteristics. Although no skewness tests were run, the median value gravitates toward the lower end of the box in the Terai and the Mountain, indicating somewhat positive skewness. The spread in the Terai for both the *CI* and the *CPI* is short, with a minimal difference between the two. The spread for both the Hills and the Mountain region is considerably longer, extending from 0.54 to 0.92 in the *CPI*, and falling slightly shorter, from 0.23 to 0.49, in the *CI*. The absence of gross outliers indicates the normal distribution of data for both the *CPI* and the *CI* in all three ecological regions.

A simple comparison (Fig. 7) of the means obtained from the two measures show differences at both regional and national levels. The difference between the *CPI* and the *CI* in the Mountain region is more than double, but in the Hills it is about a quarter, decreasing to only about a tenth in the Terai region. Fig. 7 gives an understanding that the low *CI* of the Mountain region appears to have potential for increasing production simply by increasing the crop frequency. However, this is misleading because climatic constraints are not taken into consideration in the *CI*. Thus, the *CPI* for the Mountain region would indicate that this potential is quite limited since climatic conditions limit the amount of time the land can be cropped. As argued earlier, the *CPI* takes into account the influence of climate and considers factors such as the shorter growing period and the longer crop duration. Although not as significant a difference as in the Mountain, the *CI* for the Hills indicates considerable potential (about 50 percent) for increasing intensity of cropping. In the Terai region, as expected, the difference between the *CI* and the *CPI* is much more narrow, i.e., 0.41 and 0.46 respectively. In a situation where temperature is not a limiting factor for crop cultivation, such as the Terai region of Nepal, the inclusion of climate variables makes little difference in the measurement of agricultural intensity.

As postulated earlier, the geography of cropping intensity obtained from two methods is different. It is important, however, to (a) investigate the magnitude of this variation, and (b) determine the significant differences in the *CPI* and the *CI* of the three regions. For this purpose, a one-way ANOVA was used, which assumes that the regional variance is equal. The Levene statistics of 8.146 ($p = 0.002$) for the *CPI*, and 3.988 ($p = 0.029$) for the *CI* reject the notion that there is equal variance in agricultural intensity in the three ecological regions (rejected at 0.05 level).

Tables 1 and 2 present the results from ANOVA for the *CPI* and the *CI* respectively. The *F* statistics for the *CPI* ($F = 4.574$, df $= 31$, $p \leq 0.01$) and the *CI* ($F = 4.997$, df $= 31$, $p \leq 0.01$) is significant ($\alpha = 0.01$). Tables 3 and 4 present the means (and range) for the *CI* and *CPI* respectively. Although the CVs of 0.34 for the *CI* and 0.36 for the *CPI* are nearly equal, the level of cropping intensity (CI = 0.46 and CPI = 0.61) derived from the two methods is quite different. Table 3 shows that the average intensity as measured by the *CI* is highest in the Hills, followed by the Terai and the Mountain regions. In contrast to the *CI*, the average intensity as measured by the *CPI* is highest in the Mountain region, with the Mountain and the Terai regions being significantly different (Table 4). The results of the Scheffe tests indicate that there is a significant difference ($\alpha = 0.05$) between the Mountain region and the Hills for the *CI* (Table 3) and between the Mountain and the Terai regions for the *CPI* (Table 4).

**Table 2**
Results of ANOVA, between ecological regions for the *CI*.

| Source | *n* | *df* | *SS* | *MS* | *F*-Ratio |
|---|---|---|---|---|---|
| Between group | 3 | 2 | 0.192 | 0.096 | 4.997** |
| Within group | 32 | 29 | 0.559 | 0.019 | |
| Total | 32 | 31 | 0.752 | | |

*Note*: $n$ = number, $df$ = degree of freedom, $SS$ = sum of square and $MS$ = mean square.
**Indicates significance at 0.01 level as computed by Scheffe *post hoc* analysis.

Based on the results obtained from ANOVA, the *CPI* can make inferences that the agricultural intensity is highest in the Mountain and lowest in the Terai region. This can be verified by the fact that the arable land in the Mountain region is very limited, and the farmers, in order to sustain themselves, intensively cultivate all available arable land. Furthermore, farmers have to contend with the dual climatic constraints of a shorter growing period and a relatively longer crop duration. Since the *CPI* is able to encapsulate both these factors into its measure of the intensity index, it reflects a more realistic intensity pattern. The potential for further increase in food production through multiple cropping does not exist in the Mountain, hence other avenues of agricultural development needs to be sought. The low mean of the *CPI* in the Terai region indicates lower cropping intensity, hence, the potential for increased production through increasing the frequency of cropping.

The results of the paired $t$-test (Table 5) also indicate that there is a significant difference between the mean intensity values obtained from the *CPI* and that of the *CI* across all three ecological regions of Nepal. The significance level of 0.05 is used for a two-tailed test and the null hypothesis is rejected if the calculated $t$-value is significantly different from the tabulated $t$ of alpha $= 0.025$ at $n-1$ degrees of freedom. Table 5 indicates that the $t$-statistic ($t = 6.48$, $df = 31$) is large enough for rejection of the assertion that there is no difference in cropping intensity, y irrespective of methodology. As expected, the agricultural intensity as measured by the *CPI* is higher than that of the *CI* at the national level. The mean of the paired differences between the *CPI* and the *CI* for the Terai region is 0.048 with a standard deviation of 0.008. The $t$-statistic indicates that there is a significant difference ($t = 18.40$, $df = 9$) between the two measures of the *CPI* and the *CI* in this region. This also is true in the case of both the Hills and the Mountains. In the Hills, the mean of the paired difference between the *CPI* and *CI* is 0.132 with a standard deviation of 0.042. The $t$-value ($t = 12.06$, $df = 14$) shows a significant (0.05) difference between the two measures of agricultural intensity. The $t$-statistic ($t = 6.82$, $df = 6$) of the Mountain region also indicates that there is a significant difference between the *CPI* and the *CI*.

The inclusion of the climatic variables of crop duration and frost-free growing period in measures of agricultural intensity increases the index of intensity substantially. The mean difference between the *CPI* and *CI* is lowest in the Terai (0.048), where the climate variability is least, and the highest in the Mountain region (0.368), where the climate variability is most pronounced. This reinforces the fact that the influence of climate variables in the measure of agricultural intensity is significant in the regions where the growing period is shorter. In all three ecological regions, the *CPI* values are higher than the *CI* values. The smaller difference between the mean of the *CPI* and the *CI* in the Terai region can be explained by the fact that the warmer temperature in the region creates a frost-free environment and enables crop cultivation for all twelve months of the year. Hence, inclusion of climate variables such as length of growing period and crop duration in the measure of the *CPI* has a minimum effect on the level of intensity in the Terai region, and as such accounts for the smaller difference between the *CPI* and the *CI* in this region.

Fig. 8a and b show spatial patterns of the cropping index based on the values of the *CI* and the *CPI*. Clearly the spatial patterns between the *CPI* and the *CI* are different. The patterns of intensity as calculated from the *CI* (Fig. 8a) show a significant number of districts with a very low level of cropping intensity. This is especially true in the Mountain and the Terai regions. Four out of seven districts in the Mountain region and five out of ten in the Terai region, show significantly lower cropping intensity. In the Hills, however, twelve out of fifteen sample districts show moderate to high cropping intensity. Six districts (Dadeldhura, Doti, Surkhet and Dailekh in the west and Kathmandu and Kaski in the central part of the country) show the highest cropping intensity in the Hills.

The pattern of agricultural intensity, as derived from the *CPI* (Fig. 8b), shows a different picture. The analysis of the patterns of the *CPI* reveals that the index of intensity is higher in the districts in most of the Mountain region as well as in the western Hills of Nepal. According to the *CPI* two districts (Solukhumbu and Dolakha) in the Mountain region and three (Okhaldhunga, Bhojpur and Ilam) in the Hills indicate low agricultural intensity. In the case of the Terai region, the western (Kailali and Banke) and eastern (Dhanuasha, Sunsari, Morang and Jhapa) districts show low intensity pattern. The four districts (Dang, Rupendehi, Chitwan and Makwanpur) in the central part, however, show moderate intensity pattern.

**Table 3**
Summary Results of ANOVA of the *CI* by ecological regions.

| Regions | *n* | $\bar{x}$ | $\sigma$ | Range | |
|---|---|---|---|---|---|
| | | | | Min. | Max. |
| Terai | 10 | 0.41 | 0.07 | 0.32 | 0.50 |
| Hills | 15 | $0.54_a$ | 0.17 | 0.23 | 0.76 |
| Mountain | 7 | $0.35_a$ | 0.13 | 0.18 | 0.52 |
| Total | 32 | 0.46 | 0.16 | 0.18 | 0.76 |

*Note*: Means followed by subscripts "a" are significantly different at 0.05 level.

**Table 4**
Summary Results of ANOVA of the *CPI* by Ecological Regions.

| Regions | *n* | $\bar{x}$ | $\sigma$ | Range | |
|---|---|---|---|---|---|
| | | | | Max | Min |
| Terai | 10 | $0.46_b$ | 0.07 | 0.36 | 0.55 |
| Hills | 15 | 0.67 | 0.21 | 0.29 | 0.95 |
| Mountain | 7 | $0.72_b$ | 0.28 | 0.39 | 1.09 |
| Total | 32 | 0.61 | 0.22 | 0.29 | 1.09 |

*Note*: $n$ = number of observation, $\bar{x}$ = Mean, $\sigma$ = Standard Deviation.
Means followed by same subscripts are significantly different at 0.05 level.

**Table 5**
The Result of Paired $t$-test Between the *CPI* and the *CI* by Regions.

| Pair (*CPI-CI*) | Paired differences | | | | | *t* | *df* | Sig (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | $\sigma$ | *SE* | 95% Confidence interval | | | | |
| | | | | Lower | Upper | | | |
| 1 National | 0.157 | 0.133 | 0.024 | 0.108 | 0.207 | 6.48 | 31 | 0.000 |
| 2 Terai | 0.048 | 0.008 | 0.002 | 0.042 | 0.054 | 18.40 | 9 | 0.000 |
| 3 Hills | 0.132 | 0.042 | 1.011 | 0.109 | 0.156 | 12.06 | 14 | 0.000 |
| 4 Mountain | 0.368 | 0.142 | 0.053 | 0.236 | 0.500 | 6.82 | 6 | 0.000 |

*Note*: $\bar{x}$ = mean, $\sigma$ = standard deviation, $SE$ = standard error of the means, $t$ = $t$-statistic, $df$ = degree of freedom.

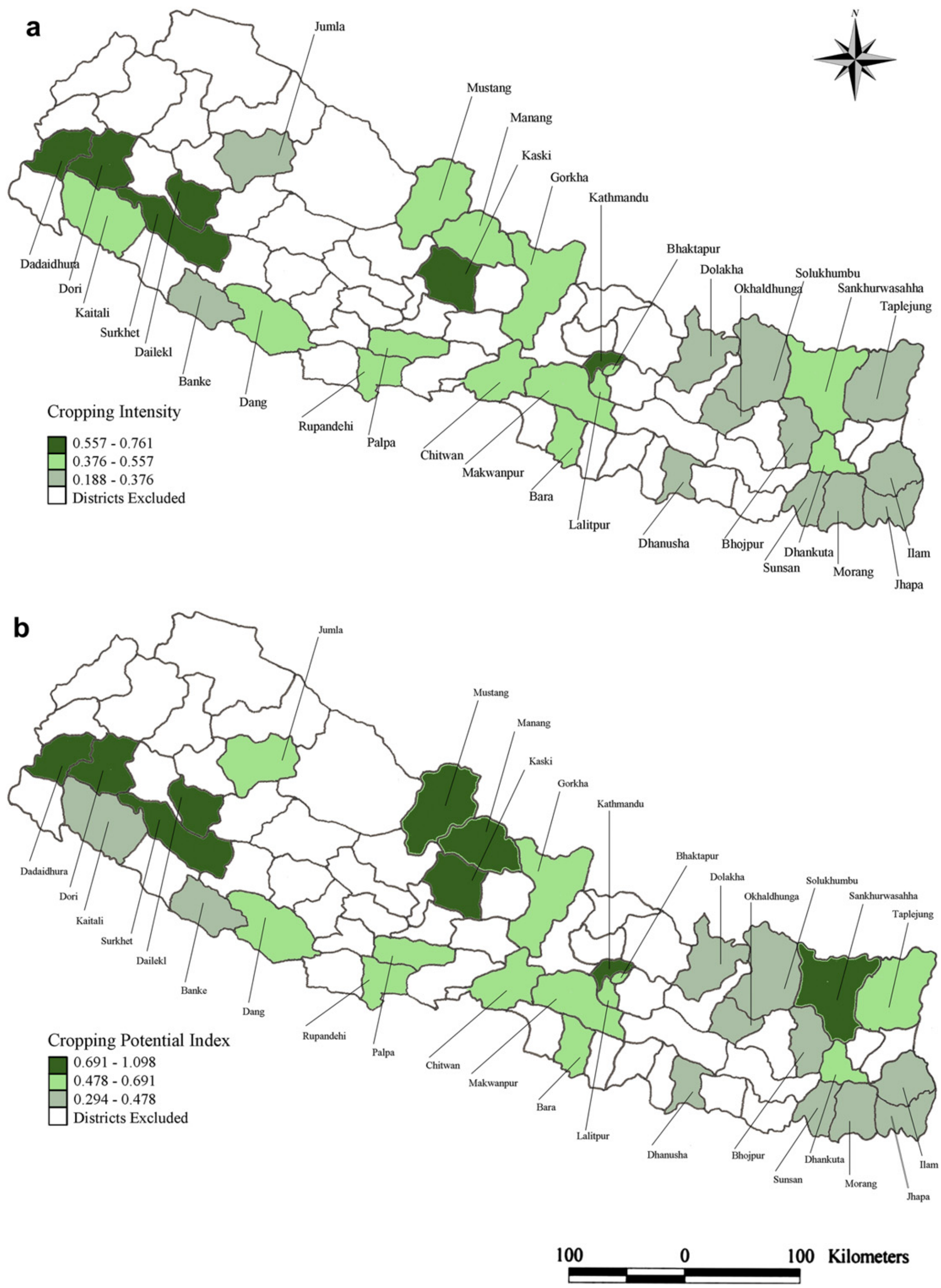


**Fig. 8.** Patterns of cropping intensity index based on the two measurement methods, the CI and the CPI.

Interestingly, in the Mountain region, the pattern of cropping intensity is quite distinct. The reason for such change is explained by the fact that this region has a shorter growing period and longer crop duration that the *CPI* is able to incorporate. The difference in the spatial pattern of intensity is not as distinct in the Hills and the Terai regions. This can be explained by the fact that, in these two regions (the Hills and the Terai) the growing period is not a limiting factor. In other words, geographic patterns of agricultural intensity are molded largely by the climatic factors in Nepal.

## Conclusion

As stated in the beginning, the main purpose of this paper is to devise and offer an alternative method to quantify agricultural intensity, and thereby facilitate the understanding of production potential. The *CPI* includes climate variables, which enable it to be adjusted to different climatic regions. A review of the literature demonstrates that none of the existing methods of measuring agricultural intensity are climate sensitive, although researchers have long raised the issue of climate and its role in describing variability in agricultural patterns. Most studies on the measurement of agricultural intensification consider climate factors constant or ignore them entirely. By treating climate as a constant factor, even though it can be highly variable over time and space, the existing methods of calculating cropping intensity underestimate the agricultural intensity of many regions. This is particularly apparent in regions where the crop duration and growing period are greatly influenced by climate. In an effort to understand the entire picture of agricultural intensity, it is necessary to use climatic factors as explanatory variables. In this case, I only incorporate the temperature as it plays a significant role in the frequency of cultivation by influencing crop duration and availability of arable land for cultivation by making frost-free conditions.

This paper addressed the apparent shortcomings of current measures of agricultural intensity by introducing climatic variables in the intensity measurement. The proposed method incorporates two climate variables of crop duration and growing period in the measurement of cropping intensity. The length of the growing period, a variable that has not been given attention in any of the conventional intensity measures, provides an upper limit for crop cultivation. Therefore, it is an important addition to the existing measure of agricultural intensity. The advantage of CPI over the more conventional methods is apparent in its ability to set a theoretical upper limit to the production potential of crops in a specific climatic region. This advantage is even more apparent in regions with short growing periods because fewer crops can mature in the available growing months.

Climate is variable in time and space and, hence, needs to be explicitly represented in indicators that attempt to measure productivity and intensity of resources use. Researchers involved in quantifying the intensity have ignored the climate that determines the "threshold level" of the intensity of land use. Below this threshold, continued cultivation is not possible, irrespective of the demand placed by either population or the market. In fact, climate can provide boundaries of constraints or optimize conditions for intensification. For example, the average temperature regime creates conditions conducive for the practice of agriculture. Given the increasing nutritional, economic and social importance of food and fiber production, it is important for today's world to find out the optimum level for food production, and to explore every possibility for optimizing resources, including climate. Therefore, any productivity measure cannot be complete unless it is climate sensitive.

The strength of the *CPI* is that it provides feedback about the average number of months available for crop cultivation and thereby gives information regarding the temporal opportunity for increasing cropping intensity through multiple cropping. For example, most of the districts in the Mountain region already have optimized the available crop growing period. In other words, the possibilities for increasing production through multiple cropping do not exist. The next stage of agricultural development in these districts entails switching toward high yielding crop varieties, the development of infrastructure, and the promotion of better crop management activities.

Similarly, most of the districts in the Hills and in the Terai show a considerable scope for improving overall production simply by means of additional cropping. The *CPI* can be applied at different spatial scales too. For example, at the district level it can be used to devise strategies for agricultural interventions. One of the applications is to design and implement cropping patterns suitable to the temporal opportunity available in the district. In the same manner, at the regional level the information obtained from the *CPI* can be applied to prioritize and coordinate the resources for agricultural planning to specific areas. This could be done to identify the districts with low intensity and coordinate with farmers and other related agencies to plan multiple cropping interventions in such areas. At the national level, cumulative information of the *CPI* from the district level can be used to identify the districts that have reached the maximum limit of crop cultivation. This information can be used to design an alternative strategy for further enhancement of agricultural production, or to set up programs in districts that still have the potential for multiple cropping. This will, in turn, allow for more precise and strategic allocation of the country's limited resources for agricultural development. In conjunction with other information, the government can use the *CPI* to guide research and development organizations working in agriculture to prioritize their programs in the field. Thus, comprehensive information provided by the *CPI* can be applied with greater reliance as a planning tool since it is considered to be a more representative measure of agricultural intensity.

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