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Assessment of the FAO traditional land evaluation methods, A case study: Iranian Land Classification method

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Running title: Assessment of the FAO traditional land evaluation methods

Abstract

Land evaluation is a critical step in land-use planning. Although many methods have been developed since the formulation of the FAO framework for land evaluation, several of the more traditional approaches still remain in widespread use but have yet to be sufficiently validated. Contrary to more recent land evaluation systems, which need lots of data, these systems only require basic soil and landscape information and provide a general view of land suitability for major types of land-use. Since, the FAO initially presented a qualitative framework for land-use planning based on two previous methods developed in Iran and Brazil, in this study, we assessed the reliability and accuracy of a traditional land evaluation method used in Iran, called Land Classification for Irrigation (LCI), comparing its results with several qualitative and quantitative methods and actual yield values. The results showed that, although the LCI is simpler than more recently developed methods, it provided reliable land suitability classes and also showed good relationships both with other methods analyzed and with actual yields. Comparisons between qualitative and quantitative methods produced similar results for usual crops (a crop rotation as: barley-alfalfa-wheat-fallow), but for opportunist crops (such as alfalfa), these methods performed differently as such crops are more dependent on incoming and market conditions than on land characteristics. In this work, using the FAO method to indicate the LCI subclasses is also suggested as this could help users or managers to know the limitations for land use planning.

Keywords: Land evaluation, Land suitability, Land Classification for Irrigation (LCI), FAO framework

Introduction

Land evaluation based on the guidelines of the UN Food and Agriculture Organization (FAO) is a critical step in land-use planning (FAO, 1993). FAO (1976) presented a qualitative framework for land-use planning based on two methods developed in Iran and Brazil. After, other methods have also been developed, including: the Sys method (Sys *et al*., 1991); ALES (Rossiter and Wambeke, 1994); MicroLEIS (De la Rosa *et al*., 2004); Land Evaluation and Site Assessment (LESA; http://soils.usda.gov; Hoobler *et al*., 2003); and Agricultural Land Classification (ALC; http://www.defra.gov.uk; MAFF, 1988). Although quantitative methods for land evaluation have also been developed (e.g. Janssen, 1990; Lanen, 1992; Nogués *et al*., 2000; De la Rosa and van Diepen, 2002; Zhang, 2004), qualitative methods are still widely used (Recatalá and Zinck, 2008; Fontes *et al*., 2009).

There are many studies in which qualitative land evaluation methods have been compared with quantitative ones or with actual yields. Hennebed *et al*. (1996) evaluated the FAO framework by comparing observed and predicted yields for five food crops in Burundi. They reported that the FAO framework was able to successfully predict the yield ranges of various crops based on climate, soil data and land-use technology. They also suggested that, since the FAO method correctly predicts mean regional farm yields, it could also be useful for land use planning. Martínez-Casasnovas *et al*. (2008) compared land suitability and actual crop distribution in an irrigation district in Spain's Ebro valley. Their results showed the existence of a significant relationship between crop location and land suitability over time. In other cases results were not very satisfactory. Rahimi-Lake *et al*. (2009) compared quantitative and qualitative land suitability methods for olive trees but the different methods did not produce similar estimations. Quantitative evaluations produced less suitable results than qualitative ones. The reason for this could bethe use of a socio-economic quantitative approach to determine land suitability. This made the results very variable, because the land suitability classes were greatly influenced by cost and income, being land suitability also dependent on the market (Rahimi-Lake *et al*., 2009). In contrast, Zali Vargahan *et al*. (2011) reported that better land suitability classifications resulted from using a quantitative method based on economic information than qualitative methods. . Safari *et al*. (2013) compared a conventional method with a geostatistical approach to assess qualitative land suitability evaluation for main irrigated crops. The results showed that the overall accuracy was poor at subclass category but it improved at class level.

The accuracy of land suitability evaluations have also been determined by comparing the predictions with values for present crops or observed yields (D'Angelo *et al*., 2000; Chen *et al*., 2003; Ceballos-Silva and Lopez-Blanco, 2003; D'Haeze *et al*., 2005; Mandal *et al*., 2005; Saroinsong *et al*., 2007).

The above suggests that different land evaluation approaches are possible, with each one having its advantages and disadvantages from the viewpoint of methodology, input data requirements and outputs. A primary question therefore arises concerning which land evaluation method is the best when we consider economic costs, the complexity of the procedure and the benefits of working with that specific method. However, there is very little scientific literature to help to make this choice (Manna *et al*., 2009). These authors compared several different methods that appeared after the FAO framework and until the appearance of simulation models (from 1976 to 2005), concluding that more complex methods gave better results in terms of their predictive ability than more simplified approaches.

In addition to land evaluations based on the FAO framework, in some countries more traditional evaluation systems are still widely used. These include local land evaluation systems used in USA, UK, Canada, Brazil, Netherlands and Iran. In 1974, the FAO (1974) published '*Approaches to land classification*' in which these systems were described. Despite several limitations, these local methods play a major role in land evaluation because they are straightforward and use simple models. Contrary to more recent land evaluation systems, the traditional ones tend to be based on qualitative models that only require basic soil and landscape data. Furthermore, they provide a general view of the suitability of land for major types of land-use, such as rainfed farming or irrigation. One example of these traditional evaluation systems is that used in Iran, where soil survey activities started in 1951. A land evaluation system called Land Classification for Irrigation (LCI) was devised in 1970 based on existing survey reports compiled by Mahler (a FAO expert) and experienced staff. This system is still widely used in Iran in soil surveys and related projects.

Although this system has been applied for more than 40 years, no study has been conducted to evaluate its reliability or accuracy. However, it attracted the attention of the FAO during the formulation of the Framework to Land Evaluation (FAO, 1976). Furthermore, a validation of such qualitative methods with parameters as actual crop yield has not been carried out yet. The main objective of the present study was to assess the performance of the Land Classification for Irrigation (LCI) method and to compare it with the most recently developed qualitative and quantitative methods, as well as with actual crop yields, to determine its reliability.

Materials and Methods

Study area

The study area (about 22000 ha), was located in the Shareza region (Isfahan province, Central Iran) (Figure 1), between 32° 0′ - 31° 15′ N and 51° 50′ - 51° 55′ E.

This area has three dominant physiographic units: plateaux, alluvial fans and a piedmont plain. The mean annual precipitation and temperature in this region are 106.6 mm and 14 °C. The mean altitude is 1800 m a.s.l. Irrigated wheat, barley and alfalfa are the main land uses in this area. According to *Soil Taxonomy* (Soil Survey Staff, 2010), the soil moisture and temperature regimes of the area are: arid and mesic. The dominant soils, Aridisols and Entisols, were described by the Agriculture and Natural Resource Research Center of Isfahan at the 1:50000 scale (Tables 1 and 2). The Entisols were located in the piedmont and alluvial plain, whereas the Aridisols were located in the plateaux. The soils in the plateaux developed on thick-bedded conglomerate massive limestone (slaty in parts). The soils in the lower parts of the area formed on dark-grey, massive limestone, well-bedded dark-grey limestone and dark shale.

Input data for land evaluation

Soil and climatic data. To obtain basic soil properties (Table 1) and to test the existing soil map, 30 soil profiles were dug in the area on the basis of a previous physiographic analysis. The locations were georeferenced with a Etrex Vista Garmin GPS. These soil profiles belonged to soils series reported on the soil map. Table 1 summarizes physical and chemical properties for representative pedons of dominant soil series in the study area. Some soil series have several phases. Differences between phases refer to properties such as slope, gravel content, erosion and soil depth.

A 10-year time series of climate data obtained from the Kabootar-abad Isfahan synoptic meteorological station was analyzed for the requirements of the different land use types considered.

Socio-economic data. There were five villages (Manoochehrabad, Jafarabad, Garmafshar, Esfeh and Jalalabad) and a city (Shahreza) in the study area. Agricultural systems and technologies used by farmers were essentially the same. The data for the socio-economic land evaluation were obtained from 100 inquiries made to random farmers (representing ~15% of farmersin the study area). Each inquiry included questions about: the costs and incomes associated with each crop together with any other relevant information. Cost included factors such as seeds, fertilizers and pesticides, labour, tillage operations, irrigation; economic benefits; the average yield of each crop (based on harvest data). For each crop, the averages of values taken from the inquiries were used as input information in the socio-economic land evaluation.

Land utilization types. There were three major land utilization types (LUT) in the study area. They were: 1-winter wheat (LUT-I), 2-winter barley (LUT-II) and 3-alfalfa (LUT-III). All crops were irrigated by surface irrigation. These LUTs were considered for each soil unit. Two typical crop rotations in the study area are barley-alfalfa-wheat-fallow and barley-fallow-wheat-fallow (in saline area).

Land evaluation methods

The four land evaluation methods most frequently used in Iran were considered. These included Land Classification for Irrigation (LCI) and three methods for qualitatively and quantitatively assessessment of land suitability (called Sys method, in Iran).

Land classification for irrigation (LCI). This is a traditional land evaluation approach developed by Mahler (1970). It was one of the two that the FAO used to develop its framework for land evaluation. Land is divided into six different categories for gravity or surface irrigation. The classification is based on increasing limitations of four major factors: soil; salinity-alkalinity; topography and erosion; and drainage (Table 3). Each major limiting factor is subsequently associated with a series of related sub-factors, giving a. total of 18 factors to be considered:

- Soil factors (S): 1: subsoil permeability, 2: subsoil stoniness, 3: top soil texture, 4: top soil stoniness, 5: soil depth, 6: limiting layer and 7: infiltration rate.
- Salinity and alkalinity factors (A): 8: salinity and 9: alkalinity.
- Topography and erosion factors (T): 10: overall slope angle, 11: transversal slope angle, 12: microrelief, 13: current (water and wind) erosion status and 14: present (water and wind) deposition status.
- Drainage factors (W): 15: groundwater depth, 16: other drainage limitations such as hydromorphic features, 17: ponding hazard and 18: flooding hazard.

Each limitation, when present, is rated separately and it is given a rating symbol. Some basic land characteristics, which may or may not be limiting, are also rated in all cases, including the factors 1, 3 and 10. These symbols are placed in a rating formula according to a standard sequence, called limitation formula. S and A are in the numerator and T and W in the denominator (Figure 2).

Table 3 shows the classes and subclasses in the LCI, which were determined based on maximum limitation factors. Table 4 shows the limitation formula for each land unit and Table 5 explains the main soil limiting factors. The details of this process are explained in Mahler (1970), Sys *et al*. (1991), Zink (1995) and Bagheri Bodaghabadi (2011). In this method, subclasses are determined by the four major limiting factors referred above: Soil (S), Salinity-Alkalinity (A), Topography (T) and Drainage (W). These symbols are added after the appropriate land class. For further clarification, the results of the LCI have been presented with the corresponding FAO subclass nomenclature. For example, in an IIT unit, the limiting factors can be: slope, microrelief, water erosion, wind erosion or deposition, or some combination of these factors. In the LCI, the symbol T can refer to any of these limitations, but in the FAO framework each limiting factor can only be shown by a single symbol. For instance, S2e indicates that the major limiting factor is erosion. Classes I, II, III, V and VI are shown as S1, S2, S3, N1 and N2 respectively. Class IV, which is based on the expert knowledge, is shown as S3 or N1 (Table 3). In contrast, if the limiting factor has a direct influence on the crop (e.g. soil depth or salinity), class IV is shown as N1, unless S3 is preferred. Although there is not a generally accepted standard framework, these land classification criteria are widely used by researchers in Iran (Bagheri Bodaghabadi, 2011).

Qualitative and quantitative methods. Three land suitability approaches for specific crops were used according to Sys *et al*. (1991, 1993). These methods consisted of matching land characteristics with crop requirements. They include maximum limitation (or simple limitation), qualitative parametric approaches and quantitative socio-economic land suitability. Soil and land characteristics were matched based on Sys *et al*. (1991) and other tables proposed by the Iranian soil and water research institute (Givee, 1997).

- In the maximum limitation approach, plant requirements are compared with the corresponding qualitative land and climatic characteristics; the maximum limiting properties define land suitability class and subclasses.
- In the *parametric method,* limitation levels are rated on a numerical scale ranging between a maximum value of 1 (or 100%) and a minimum value of 0. A land index (I) is calculated from the individual rating values of all the characteristics, multiplied by 100. This index can be calculated from several different procedures, which include: the summation, Storie index and square root (SR) methods. In this study we used SR to calculate the land index (I); the related equation is:

$$I = R_{\min} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \ldots}$$

where:

I is the specified land index, A, B, etc., are different ratings for each soil property, and R_{min} is the minimum rank or value. The suitability classes and limiting factors (subclasses) are then determined as shown in Table 6; see Sys *et al.* (1991) and Bagheri Bodaghabadi (2011) for further details.

- Marginal, observed and predicted yields are required to determine quantitative land suitability. In this study, the agro–ecological zoning (AEZ) model was used to calculate potential yield (Kassam, 1977). The equation is:

$$Y = \frac{0.36\ \text{bgm} \times \text{KLAI} \times \text{Hi}}{\left[\left(\frac{1}{L}\right) \times 0.25\text{Ct}\right]}$$

where:

Y = potential yield (kg ha^{-1}), bgm = maximum gross biomass production rate (kg CH_2O ha^{-1} $year^{-1}$), KLAI = leaf area index at maximum growth rate, Hi = harvest index, L = growth cycle (day) and Ct = Respiration coefficient (see Appendix for more information).

Potential yield can be determined from climatic data (such as solar radiation and mean temperature) and plant characteristics. Marginal yield is the part of the yield in which there is neither profit nor loss. It is also the level of productivity that results in total income being in equilibrium with the total cost. It can be calculated from the quotient of total cost and total income for each yield unit (kg).

The data required and the actual, or observed, yield for each land unit were obtained from the questionnaires completed by farmers and also from the local Agricultural Extension Service.

Land classes were then calculated as follows:

- The marginal value between classes S1 and S2 was equal to 75% of potential yield.
- The marginal value between classes S2 and S3 was equal to 1.4 times the marginal yield.
- The marginal value between classes S3 and N was equal to 90% of the marginal yield.

Predicted yield can be obtained from potential yield multiplied by the soil index (*SI*). It is worth noting that *SI* is as in *I* (land index) but without the climate index

(CI); on the other hand: $I = SI*CI$. For example, in the study area CI_{wheat} = 0.82 and for unit 1.1, SI_{wheat} = 0.38, then $I_{1.1}$ = 0.82*0.38 = 0.31. Additionally, regression and correlation statistical analyses were applied, using observed yield and predicted yield to determine the accuracy and statistical significance of the selected land evaluation method.

Comparison of land evaluation methods

Index of land suitability. To compare the quantitative and qualitative land suitability methods with the LCI method, it was necessary to obtain average land suitability values for the main crops grown in the study area. The numerical values of the land indexes (I) were assigned to all the crop rotation combinations. Then an index of land suitability (ILS) as defined by Bagheri Bodaghabadi (2011) was used to compute the average of the different I ranges. The ILS formula is:

$$ILS = \sum_{i=1}^{n} \frac{I_i \ Pc_i}{Cr_{tot}}$$

where:

I_i = land index for the i^{th} crop, Pc_i = planting cycle of the i^{th} crop and Cr_{tot} = total time or duration of the crop rotation. For example, the usual crop rotation in the study area is 'barley, alfalfa, wheat and fallow', in which the Pc is: 0.6, 7.0 and 0.6 years, respectively, for crops with an additional 0.3 years for fallow; the total Cr_{tot} is therefore 8.5 years. For example, ILS in unit 1.1 can be calculated as following:

$ILS_{1.1}$ = (31.35 * 0.6 + 28.45 * 7.0 + 33.00 * 0.6) / 8.5 = 27.97

Accuracy analysis. The performance of the land evaluation methods was quantitatively assessed by map overlaying and computing of error matrices. The error matrix permits the calculation of a range of measures that describe the accuracy of one method with respect to the other. The Overall Accuracy (OA) (Congalton and Mead, 1983) is the percentage of correctly classified or predicted areas with respect to the total number sampled.

$$OA = \frac{\sum_{i=1}^{n} X_{ii}}{\sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij}} \quad , \quad \sum_{i=1}^{n}\sum_{j=1}^{n} X_{ij} = n_{tot}$$

Where:

X_{ii} = diagonal elements in the error matrix, or similar land evaluation classes, X_{ij} = the surface area in the *ith* row and the *jth* column, i = rows which show the first method (from 1 to n), j = columns which show the second method (from 1 to n), n = the number of classes and n_{tot} = the total surface area in the error matrix.

Results and discussion

Table 4 shows the results for the different methods employed for land evaluation. The most frequent land suitability classes used in the study area are the marginal (S3) and non-suitable (N1). Although some land units are moderately suitable (S2), they may have land indexes that border on being marginally suitable (Table 4). The climatic evaluation showed that the area had moderate suitability (S2) for all of the major crops selected for the study. The main limitation was imposed by the mean temperature of the growing cycle (data not shown). Table 5 shows the main soil limiting factors. These include: soil salinity, soil depth and top soil stoniness.

Potential yield was estimated for the major crops. These values were: 8.9, 9.0 and 22.1 ton ha^{-1} for wheat, barley and alfalfa, respectively. Because of soil limitations, no land unit reached these potential values and, under the best conditions, the maximum actual yields were: 4.5, 5.0 and 12.5 ton ha^{-1} for the previously mentioned crops. Marginal yields were calculated from the inquiries completed by farmers and using the costs and incomes obtained from them. According to this, the marginal yields were: 2.7, 2.7 and 6.0 ton ha^{-1}, respectively, for the studied crops. As shown in Table 4, some land units had actual yields that were smaller than the marginal values, but this land was still cultivated. In these cases, it is supposed that farmers do not expect to obtain any profit from these land units. A first question therefore arises: why are these land units cultivated? One reason is that farmers pay very low salaries or use family labour, which reduces the marginal yield. Irrigation water is very cheap too, which also favours a reduction in the marginal yield. However, these costs should be included in the land evaluation analysis for socio-economic land suitability. Similar results were also obtained from other studies, but none of them explained why land was dedicated to agricultural use when the actual yield was less than the marginal one (e.g. Rahimi Lake *et al.*, 2009; Zali Vafgahan *et al.*, 2011; Rabati *et al.*, 2012).

Figure 3 shows the relationship between estimated yield and actual yield. The coefficients of determination (R^2) for the linear regressions between the estimated and actual yields for each crop were high: 0.914, 0.895 and 0.950 for wheat, barley and alfalfa, respectively, with p-value<0.001. There were also high correlations between the land indexes and actual yields (Pearson correlations equal to 0.97), which confirmed the last result. It is worth noting that for the land units which were not suitable (N1 and N2), i.e. land units 2.2, 2.3, 3.1 and 7.4, the actual yields were higher than the potential ones. On these non-suitable land units, farmers have learned how to manage land resources well, except when they cannot obtain any return. Under better conditions, as in the case of land units belonging to classes S2 and S3, actual yield is usually less than predicted.

A comparison of the land evaluation classes is presented in Table 7. With the exception of the socio-economic land evaluation of alfalfa, all the land evaluation methods had high OAs. As there was a good price for alfalfa in the study area at the time, the quantitative method calculated better land evaluation classes than for other crops. Similar results have also been reported by other authors, who stated that socio-economic land evaluation is highly dependent on the market (e.g. Rahimi Lake *et al.*, 2009; Zali Vafgahan *et al.*, 2011; Rabati *et al.*, 2012). In fact, the price of alfalfa varies a little, depending on the location and the distance between farms and the market. Furthermore, alfalfa has a local price, while wheat and barley have prices regulated by the government, which makes that they are not as dependent on the market as alfalfa. Consequently, and as shown in Table 4, quantitative and qualitative land evaluations produced approximately similar results and high OAs, as shown in Table 7.

Contrary to the more recently developed land evaluation methods, which evaluate land units for each crop separately, the land evaluation (LCI) method presents a general view of the land suitability for major crops. To compare the LCI with reality it is therefore necessary to know the average potential of the land. In this case, the ILS was calculated on the basis of the main crop rotations in each land unit (Table 4). Figure 4 shows the relationship between the ILS and LCI classes. Since the correlation between actual yield and the ILS for each crop was significantly high (Pearson correlations equal to 0.96, 0.94 and 0.97 for wheat, barley and alfalfa), the ILS could be considered to be an index that indicates the actual land suitability of the land units. On the other hand, the relationship between the ILS and LCI classes is indicative of the relationship between the real value of land destined for agricultural uses and the LCI classes. There was a high R^2 between the ILS and LCI classes (Figure 4), which proves that the LCI estimations had a high correlation with reality. Manna et al. (2009) also showed that different methods had different correlations between biomass and suitability classes. According to the regression equation between the ILS and LCI classes, the average value for ILS classes S2, S3, N1 and N2 were: 49.7, 34.2, 18.7 and 3.3, respectively. In contrast, class S2 was very similar to class S3 in the study area. One reason for this could be alfalfa, which is an opportunist crop. However, it seems that profit maximisation is one of the main factors determining crop choice. Although the qualitative land suitability for alfalfa was almost marginally suitable (S3), the quantitative land suitability was S2 (Table 4). Farmers therefore prefer to cultivate this crop because it provides higher incomes. A similar result was reported by Martínez-Casasnovas *et al.* (2008) for opportunist crops such sunflower in Spain, which was very much influenced by European Union subsidies during the study period.

The LCI system was also compared with more recently developed ones (Table 4). Although it can be seen that this method can be used for land evaluation, there were some problems with class IV. As previously mentioned, LCI class IV is shown as S3 or N1, based on the FAO method (Bagheri Bodaghabadi, 2011). For example, the main limiting factor for land units 2.2 and 2.3 is soil depth and for land unit 3.1, it is salinity. Since these limiting factors have direct influences on crops, class IV is shown as N1. The results of this transformation are also presented in Table 4. The transformed LCI classes presented a highly significant relationship with others that were calculated based on more recent land evaluation methods. Table 8 shows the OA between the LCI and the other methods. Except for alfalfa in the simple limitation

(SL) and quantitative (C(qn)) methods, the OA was high for the different land utilization types considered. Even so, it can be seen that the LCI system had a significant relationship with more recent methods and also with reality.

As the main limiting factors in the study area refer to soil physical properties and salinity, a complete comparison between subclasses could not be carried out. As Table 4 shows, the subclasses were almost similar for all of the different land evaluation methods; even so, it should be remembered that the LCI system cannot show climatic limitations because it was developed for soil and land but not for climate. However, numerous studies have shown that climate is not an important limiting factor, nor one of the main ones. This is logical because based on farmers' experiences, crops that are cultivated in a given region are adapted according to its climate conditions. Furthermore, it seems that using only four symbols for the major types of limiting factors one cannot explain the type of each specific limitation very well; this therefore needs some revision. For example, in land unit 6.1, classified as IIS, the limiting soil factor, S, refers to a complex limitation of permeability, soil texture and top soil stoniness, but in land unit 8.1, classified as IISA, the S only refers to top soil stoniness. However, based on the FAO approach, each limiting factor is identified with a single symbol (FAO, 1976; Bagheri Bodaghabadi, 2011).

Conclusions

The present study compared the efficiency and reliability of a traditional land evaluation method: the Land Classification for Irrigation (LCI) system, with other more recently developed methods. Actual yields were used as an independent data set for validating the methods.

Comparisons of qualitative and quantitative methods produced very similar results for usual crops; however, for opportunist crops (such as alfalfa in the study area) the methods produced different results. This is because such crops are more dependent on market conditions than on land characteristics.

The outcomes of the accuracy analysis demonstrated that simple limitation and quantitative methods produced approximately the same estimations but that the root square method produced some different results; even so, the results were acceptable in all the analysed cases.

According to the OA between the LCI system and more recently developed methods, the LCI had highly significant relationships with the other predictions and also with the actual yields. Furthermore, even though the LCI is simpler to apply than the other compared methods, it still provides reliable land suitability classes. However, the LCI exhibited several problems, especially when it came to identifying limitations (subclasses). The LCI system considers 18 soil and land properties, which can be easily measured, but only uses four major symbols (S, A, T and W) to show 18 properties. Thus, we suggested using the FAO method for subclasses, as each limiting factor can be shown with its own symbol. Then, the transformation of the LCI system results to the FAO method provides users or managers with precise information to recognize potential limitations.

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Figure 1. Location of the study area in the Shareza region, Isfahan, Central Iran (Squares in the soil map show representative profiles)

Figure 2. Limitation formula: S, A, T and W factors refer to the main limitations and each box places a symbol for a related sub-factor

Figure 3. Relationship between estimated (Sys method) and actual (observed) yield.

Figure 4. Relationship between ILS and the LCI classes.

Figure 5: Average ralationship between *Pm* and *Tmean* (˚C) for crop groups I to IV (FAO, 1981). Note; Crop groups I: C3 species with optimum photosynthesis at 15-20 ˚C. Crop groups II: C3 species with optimum photosynthesis at 25-30 ˚C. Crop groups III: C4 species with optimum photosynthesis at 30-35 ˚C. Crop groups IV: C4 species with optimum photosynthesis at 20-30 ˚C.

Figure 6: Relationship between LAI and KLAI (FAO, 1981)