

# CHARACTERIZATION OF WHEAT GROWING ARGO-ENVIRONMENT USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

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**KEY WORDS:** Agro –environment, Remote Sensing, Geographic Information System, Advanced Wide Field Sensor (AWiFS)

### ABSTRACT:

In most of the Asia Pacific countries wheat is being grown as a main cereal crop to meet the needs of food requirements. Information of wheat growing environment and mapping of different wheat growing environmental factors viz. soil, climate, hydrology (water quality, availability) etc. are of great importance for agricultural management and planning for higher production of wheat for national food security. Remote Sensing and Geographic Information System (GIS) are the proven technology to characterize crop growing environment and operational for optimum land use planning to enhance agricultural production. In the present study an attempt has been made to characterize the wheat growing environment of Sirsa district of Haryana state, north-western India as a pilot study using Remote Sensing and GIS. The satellite data used for the present study is temporal IRS-P6: AWiFS data having 60 m spatial resolution for the Rabi crop season (January to early February 2004). Wheat crop acreage was assessed by complete enumeration digital classification method. Visual interpretation was followed for generation of soil map. Other thematic maps (Ground water depth and quality maps) were digitized using ARC GIS. Integration of all the thematic maps and analysis were carried out in ARC-GIS environment. In the study area, wheat cropped lands can be grouped into four classes depending on the yield per unit area - Wheat1 (40-50 q/ha); Wheat2 (30-40 q/ha); Wheat3 (20-30 q/ha) and Wheat 4 (<20q/ha). Wheat1 was found to grow on the Ghaggar River plain. Soils are clay loam to loam (Fine loamy Typic Haplustepts) and ground water quality is very good which is being used as irrigation through deep tube well. Whereas Wheat4 produces very low yield (<20q/ha) which is grown on sandy soils, developed over aeolian sand dunes. In this area ground water depth is relatively high and quality is not very good (brackish). The dominant soils are Typic Ustipsammments. These observations were confirmed in field also. Wheat2 and wheat3 are grown in the transition area that gives the intermediate yields. From this study, it can be concluded that Remote Sensing and GIS technologies are the potential tools for characterization of wheat growing environments for effective agro-management.

## 1. INTRODUCTION

Wheat is the most popular staple food grain all over the globe. Wheat is grown in varying environments that extend from the Arctic Circle to near the Equator, from sea level to elevations of 4,000 meters, and under very dry and very wet conditions. However the yield of wheat depends on a large number of agro-physical factors. They are soil type, climate, ground water depth and quality. Generally wheat is best grown in mild winter climate (temperature around 15°C) under irrigation conditions

The world population continues to grow geometrically. The increasing population, urbanization and industrialization, land degradation (soil salinity/alkalinity, waterlogging, soil erosion and so on) and municipal dumping are the major cause of decreasing per capita arable land. In India on an average per capita is less than 0.2ha (Pimentel et al., 1994, FAO 1997). On the other hand, the demand for food and shelter is also

increasing. So to feed people we have to grow more and more food from the limited arable land (Brown, L.R. 1995; Gadgil and Rao 2000; Kendall, H.W., and D. Pimentel. 1994.)

To have a good harvest we have to adapt improve technology with proper management of wheat growing environment. For optimum management of wheat growing environment, there is a need of thorough understanding the characteristics of environmental parameters responsible for wheat yield (Reynolds, 2000). So the detailed characterization is essential for the increase of wheat production. The detailed characteristics of wheat growing environment and their impact on wheat production is lacking in India.

Remote sensing and geographic information system based methodology have the potential, to capture the temporal variability as well as spatial heterogeneity of the agro-environmental parameters and their effect on crop conditions (RS and NAS. 1992; Parihar and Navalgund 1992).

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So, in the present study an attempt has been made to characterize the wheat growing agro – environment using Remote sensing and GIS with following specific objectives –

- To determine important wheat growing environmental Parameters;
- To characterize the wheat growing agro-environments for optimal output

## 2. GENERAL DESCRIPTION OF THE STUDY AREA

Dominant winter crop for Haryana is wheat. Sirsa district possesses heterogeneity in terms of soil ,physiography ,microclimate ground water depth and quality. That is the possible reason to select the Sirsa district as the study area.

### 2.1 Location and extent:

The study area dominated by agricultural and is surrounded by States of Punjab (Firozpur, Faridkot, Bhatinda ), bordered north side, Fatehabad district of Haryana in the East and Rajasthan state (Ganganagar district),bordered on the South and the West northern part respectively . The study area is situated in between the latitudes 29<sup>o</sup> 13' 22"N to 29<sup>o</sup> 59' 27"N and longitudes of 74<sup>o</sup> 28' 36" E to 75<sup>o</sup> 18' 14"E. It occupies a total geographical area of about 42.77 sq km. The average relief is about 200m.

### 2.2 Irrigation and Quality of Underground Water

Canals and tube wells are the two major sources of irrigation in the district. Sirsa district, canal is main source of irrigation. The area is also irrigated by tube wells during the crop season when there is a paucity of canal irrigation. So quality of ground water is also very important. However, significant portion of net sown area of the district ( about 45 %) is rain fed agriculture. Only along the course of he Chaggar river the ground water quality is good. The water of the district is saline having moderate to high electrical conductivity. There is a wide variation in the ground water depth ranging from 1.6 m to 30.0 m.

### 2.3 Soils

According to the old system soil classification the soils of Sirsa district have been grouped into 2 great groups, namely, sierozem and desert soils. As per the taxonomic classification 8 great groups have been recognized (Dahiya *et al*, 1988). These are Ustochrepts Camborthids, Ustic Torripsamments, Typic Torripsamments, Typic Camborthids, Fluventic Camborthids, Vertic Ustochrepts, Typic Haplustepts, Fluventic Camborthids. The soils are very deep and light to medium in texture. The geographical area under different texture are 31.1%, 14.7%,and 54.2% s under Coarse loamy , fine loamy, and sandy respectively.

## 2.4 Climate

Climate is most important factor of physical environment controlling the agriculture and land use. There is a variation in the annual rainfall in various part of the district. It varies from less than 300 mm to 400mm. About 75-80 percent of the annual rainfall is received from July to September which coincides with the growing season of the Kharif crops. The rest received during the post monsoon months (October to march) which coincides with the growing season of the Rabi crops. Mean temperature during the Kharif season is 34<sup>o</sup>C and Rabi season is 16.4<sup>o</sup>C respectively. Occasionally very high temperatures (44.9<sup>o</sup>C) during summer months (May/June) and very low temperatures (even 0<sup>o</sup>C or below) during winter months (December-February) are experienced.

## 3. DATA USED

**Satellite Data:** Two seasons IRS-P6 AWiFS acquired on 10th January 2004 and 03<sup>rd</sup> February, 2004

**Collateral Data:** Survey of India Toposheets (1:250 000 scale) No 44O, 44K second edition; Soil map (scale 1:250000) (source: NBSS&LUP.,Nagpur); Ground water quality map, and Ground Water depth map scale (1:500 000) (Directorate of Agriculture Haryana),

**Meteorological Data:** Rainfall data and Temperature data (average of past tenyears)

**Field information and ground truth:** Using hand held mobile GPS coordinates of ground truth information was recorded for each and every sites for training sets and post classification accuracy checking. Some soil profile observations were taken for soil characterization and confirmation of soil units.

## 4. METHODOLOGY

The work has been carried out in following steps:

### 4.1 Pre-field study.

- Preparation of base map: A boundary and main roads of state and district has been traced out from topographic maps
- Prefield interpretation of IRS P6 AWiFS data was carried out for identification and mapping different categories of wheat based on the vigor and yield
- Preparation field planning and Selection of field check point for ground truth collection and correction of prefield interpreted map.

## 4.2 Field work

In order to collect the ground truth data and field verification of pre-field interpretation, the fieldwork was performed. During the field survey and actual condition of wheat crops were checked and verified interpreted map. Based on the field observation necessary corrections were incorporated in wheat map. Some soil sample were collected and their morphology were recorded in the field for characterization of soils of the districts.

## 4.3 GIS database generation and analysis

Wheat type map was corrected and finalized and made ready for digitization. Collected data and maps were digitized for the study. Different thematic maps namely soil, rainfall, water depth and quality maps were digitized and made coverage using Arc-GIS. All the input maps and wheat map were put into database for integration and analysis.

Pair wise (wheat+soil, wheat+rainfall, wheat+ ground water depth, wheat+ground water quality) integration were carried out to examine the influence of individual wheat growing environmental parameters over wheat yield and vigor. Finally all the thematic layers were integrated together with wheat map to analyze the combine effects over wheat growth and yield and to characterize the wheat growing environments. This was carried out by union command under Arc GIS environment. Detailed of methodology were shown in Figure 1

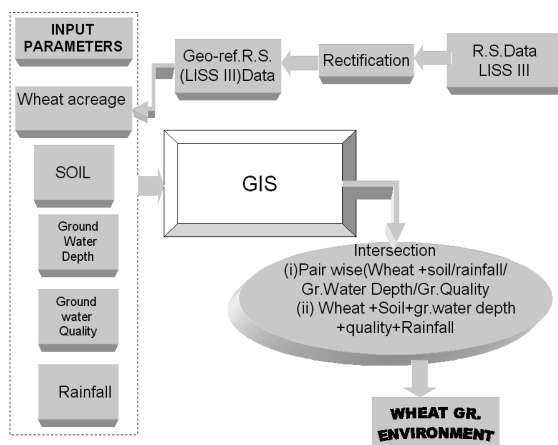


Figure1. Sequential Flow of the Methodology

## 5. RESULT AND DISCUSSIONS

### 5.1 Wheat Crop Inventory

In the study area four categories of wheat crop cover classes based on vigour were identified using digital IRS-P6 AWiFS satellite data dated 10-01-2004 and 03-02-2004. The wheat category I (very high vigour wheat, Yield 40-50 q/ha) appeared in bright red colour with smooth texture; wheat category II (high vigour wheat, 30-40 q/ha) pinkish red colour with medium to smooth texture; wheat category III (medium vigor

wheat, 20-30 q/ha) in reddish colour with medium to coarse texture and category IV (low vigour wheat, <20 q/ha) appeared in dull red colour with very coarse texture. Other land cover classes observed were waste land, current fallow land and built up area. The location and area statistics of different categorized of wheat are shown in table 1.

Table 1. Area statistics for different wheat categories and other landcover classes

| Serial No | Wheat category                | Area (km <sup>2</sup> ) | %      |
|-----------|-------------------------------|-------------------------|--------|
| 1         | Very high vigour (40-50 q/ha) | 1060.4                  | 24.79  |
| 2         | High vigour (30-40 q/ha)      | 773.6                   | 18.09  |
| 3         | Medium vigour (20-30 q/ha)    | 186.4                   | 4.36   |
| 4         | Low vigour (<20 q/ha)         | 896.8                   | 20.97  |
| 5         | Mustard                       | 110.0                   | 2.57   |
| 6         | Current Fallow                | 131.0                   | 3.06   |
| 7         | Waste land (Sand dune)        | 873.9                   | 20.43  |
| 8         | Water body                    | 5.0                     | 0.12   |
| 9         | Built up area                 | 239.8                   | 5.61   |
| Total     |                               | 4277.0                  | 100.00 |

The data in table -1 indicated that high to very high vigour wheat categories covered 42.8% of the study area. This is because, in these areas wheat are grown as well managed irrigated crop. About 21% of the area is covered with low vigour wheat crop. In the low vigour wheat growing areas, soil degradation and ground water salinity are the dominant factors affecting wheat crop growth and yield. Mustard is another dominant crop in the area with coverage of 2.6% area. Large part of area is under waste land category covering 20.4% of the study area.

### 5.2. Agro – environmental Characteristics

**Rainfall:** Only two patterns of rainfall were noticed in the area. These are <300 mm and 301- 400 mm. It was observed 301-400 mm rainfall pattern covers maximum area.

**Ground water depth:** This area is experienced 4 ground water depth classes which are <3.0 m, 3.0-10.0 m; 10.0-20.0 and 20.0-30.0 m. However only small part of the district has <3.0 m ground water depth and major part of the district has 3.0-10.0 m ground water depth. Third class 10.0m-20.0 m depth covers considerable area of district. Fourth category (20-30.0 m depth) covers (second lowest) covers fair amount of area. So the study area is rich ground water.

**Ground water quality:** A total of three classes ground water quality was observed (NBSS&LUP) in the area of interest. The classes are good that have low salinity and sodicity ( $EC \cdot 10^6 < 2000$ ,  $SAR < 10$ ), moderately good ( $EC \cdot 10^6$  2000-4000,  $SAR > 10$ ) and marginally suitable for irrigation ( $EC \cdot 10^6 = 4000-8000$ , saline,  $SAR < 10$ ). The class 3 covers maximum area flowed by class 1 then class 2.

**Soils.** In study area there are 8 dominant soil classes observed. These are Fluventic Camborthids, Typic Camborthids, Typic Torripsamments, Typic Ustifluvents, Typic/Vertic Ustochrepts, Ustic Torripsamments and Ustochreptic Camborthids. Most of the soils are well drained to excessively drained, texture of the soils ranges from sandy to fine loamy. Fine loamy texture was observed for Typic/Vertic Ustochrepts and sandy texture was observed for Torripsamments developed over sand dunes. The area distribution under different texture, drainage, slope and erosion was presented in table 2

Table 2. Area statistics for different soil characteristics

| S. N. | Soil characteristics | Soil class                                | Area km <sup>2</sup> | Area % |
|-------|----------------------|---|----------------------|--------|
| 1     | Texture              | Coarse loamy                              | 1595.3               | 31.01  |
| 2     |                      | Fine loamy                                | 757.0                | 14.72  |
| 3     |                      | Sandy                                     | 3439.6               | 54.27  |
| 4     | Drainage             | Excessively drained                       | 2803.0               | 54.50  |
| 5     |                      | Moderately well drained                   | 6035.7               | 11.73  |
| 6     |                      | Well drained                              | 1737.3               | 33.77  |
| 7     | Erosion              | Moderately eroded                         | 3715.0               | 72.22  |
| 8     |                      | Severely eroded                           | 59.2                 | 1.15   |
| 9     |                      | Slightly eroded                           | 1369.7               | 26.63  |
| 10    | Slope                | Gentle slope                              | 312.1                | 0.51   |
| 11    |                      | Nearly level plain                        | 1291.1               | 25.01  |
| 12    |                      | Nearly level plain with sand dunes        | 78.6                 | 1.53   |
| 13    |                      | Very gently sloping plain                 | 3596.4               | 69.92  |
| 14    |                      | Very gently sloping plain with sand dunes | 14.6                 | 0.03   |

Wheat map and rainfall map were integrated and analyzed. It was observed that there is no significant relationship between wheat categories and rainfall because farmers use irrigation. This activity minimized the effect of rainfall

Wheat map was integrated with ground water quality map. It was observed suitably irrigation water is available in the south eastern part of the district and small area in the Ghaggar plain. Major part of the area has ground water that is not suitable for irrigation water due to salinity and sodicity. After critically examining the integrated wheat and ground water quality map, it was observed there was no significant relationship between the wheat category and ground water quality. So it may be inferred that ground water quality has minimum impact on wheat yield and vigour. Similar observation was also noticed for the integrated map comprised wheat ground water depth and quality.

Wheat map was integrated with soil map to generate a composite map (wheat+soil). It was observed in the composite map (Figure 17.) very high vigor (40-50 q/ha) wheat is confine

to fine loamy Typic / Vertic Ustochrepts and coarse loamy Typic Ustifluvents. High vigor (30-40 q/ha) wheat was observed on the coarse loamy Typic Camborthids/Fluventic /Camborthids. Low vigor wheat in association with mustard is common on Typic/Ustic Torripsamments. Medium vigor wheat (20-30 q/ha) are grown on remaining area. So it was observed soil plays the major role in wheat cultivation. Hence, it may infer that soil is one of the most key environmental parameter among the wheat growing agro-environment

After overlaying wheat map over rainfall, ground water depth and quality maps, it was observed high vigour wheat was observed in low rainfall (<300mm), and very deep ground water table, and ground water having high contents salinity and sodicity. Opposite relationship was also noticed in case of category for (low vigour, yield <20 q/ha) for high rainfall (300-400 mm) area that have shallow ground water table and good quality of ground water. Hence it may be inferred that climatic parameters, ground water table depth and ground water quality have minimum impact on wheat yield in the study area, because of intensive canal irrigation.

### 5.3 Characteristics of Wheat Growing Agro - environment

Characteristics of different wheat growing environment are presented in Figure 2 and table 3. The very high vigor (40-50 q/ha) was grown on Typic/Vertic Ustochrepts and Typic Ustifluvents. Soil texture ranges for this category of wheat is coarse loamy to fine Loamy. Here number of irrigation is also less than the low vigour wheat which is grown on the Typic /Ustic Torripsamments. The characteristics of different environmental parameters for the very high vigour (40-50 q/ha) are coarse loamy to fine Loamy soil texture, >10.0 m ground water depth moderate quality of ground water (EC\*10<sup>6</sup>, 2000-4000 SAR >10). High vigour (30-40 q/ha) are grown on the Fluventic / Typic Camborthids having texture sand to coarse loamy. Of course, some exceptional polygons were observed for the later category wheat where texture is fine loamy and soil is Typic Ustochrepts. Similar observations were also noticed for category. But there was for such polygons are very less. The low vigour wheat (>20 q/ha) was confine to Typic Torripsamments and Ustochreptic Camborthids. The texture, drainage, slope, erosion, rainfall, ground water depth and quality are sandy to coarse loamy, excessive, gentle to moderate (3-5%), moderate to severe erosion, <300, 300to 400mm, >10m, moderately good quality for irrigation respectively.

## 6. CONCLUSIONS

- ❖ Agro – physical parameters like soil characteristics, ground water depth and quality, rainfall and air temperature etc. can be combined for characterization of wheat growing agro-environment.
- ❖ Ground water depth, ground water quality, and rainfall have insignificant influence because the whole of the study area is under canal irrigation, although it was observed they have significant influence over wheat growth and yield in rain fed area as well as tube well irrigation.
- ❖ Among the all wheat growing environmental parameters soil has shown maximum influence over wheat growth and

yield. For example high vigour wheat (40-50 q/ha) has been observed on fine loamy Typic/Vertic Ustochrepts and coarse loamy Typic Ustifluvents.



Figure 2. Spatial pattern of wheat growing agro – environment

**Legend**

- Wheat class; Soil texture, Drainage, Erosion, Rainfall, Ground Water Depth and Quality
- Very high vigor wheat (40-50 q/ha); Fine loamy; Moderately well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Fine loamy; Moderately well drained; Slightly eroded; <300 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Fine loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Sandy; Excessively drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Coarse loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Coarse loamy; Well drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Very high vigor wheat (40-50 q/ha); Sandy; Excessively drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Coarse loamy; Well drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Coarse loamy; Well drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Coarse loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Coarse loamy; Well drained; Slightly eroded; <300 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Fine loamy; Moderately well drained; Slightly eroded; <300 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Fine loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Sandy; Excessively drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Sandy; Excessively drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - High vigor wheat (30-40 q/ha); Sandy; Excessively drained; Severely eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Fine loamy; Moderately well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Sandy; Excessively drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Fine loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Coarse loamy; Well drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Sandy; Excessively drained; Severely eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Coarse loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Medium vigor wheat (20-30 q/ha); Coarse loamy; Well drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Coarse loamy; Well drained; Moderately eroded; 301-400 mm; 1.6-3.0 m; Good
  - Low vigor wheat (<20 q/ha); Coarse loamy; Well drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Coarse loamy; Well drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Coarse loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Coarse loamy; Well drained; Slightly eroded; <300 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Fine loamy; Moderately well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Fine loamy; Moderately well drained; Slightly eroded; <300 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Fine loamy; Well drained; Slightly eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Sandy; Excessively drained; Moderately eroded; 301-400 mm; 1.6-3.0 m; Good
  - Low vigor wheat (<20 q/ha); Sandy; Excessively drained; Moderately eroded; <300 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Sandy; Excessively drained; Severely eroded; 301-400 mm; >3.0 m; Moderate
  - Low vigor wheat (<20 q/ha); Sandy; Excessively drained; Moderately eroded; 301-400 mm; >3.0 m; Moderate
  - Others

Table 3. Characteristics of wheat growing agro - environment

| Class N | Crop type                          | Soil texture | Drainage                | Rainfall   | Ground Water Depth | Ground Water Quality |
|---------|------------------------------------|--------------|-------------------------|------------|--------------------|----------------------|
| 1       | Very high vigor wheat (40-50 q/ha) | Fine loamy   | Well drained            | 301-400 mm | 10m-20m            | Moderate             |
| 2       | Very high vigor wheat (40-50 q/ha) | Fine loamy   | Moderately well drained | 301-400 mm | 20m-30m            | Moderate             |
| 3       | Very high vigor wheat (40-50 q/ha) | Fine loamy   | Moderately well drained | <300 mm    | 10m-20m            | Moderate             |
| 4       | Very high vigor wheat (40-50 q/ha) | Coarse loamy | Well drained            | 301-400 mm | 10m-20m            | Moderate             |
| 5       | High vigor wheat (30-40 q/ha)      | Fine loamy   | Well drained            | 301-400 mm | 3m-10.0 m          | Moderate             |
| 6       | High vigor wheat (30-40 q/ha)      | Fine loamy   | Well drained            | 301-400 mm | 3m-10.0 m          | Moderate             |
| 7       | High vigor wheat (30-40 q/ha)      | Fine loamy   | Moderately well drained | 301-400 mm | 3m-10.0 m          | Moderate             |
| 8       | High vigor wheat (30-40 q/ha)      | Coarse loamy | Well drained            | 301-400 mm | 3m-10.0 m          | Moderate             |
| 9       | High vigor wheat (30-40 q/ha)      | Coarse loamy | Well drained            | <300 mm    | 10.0 m-20m         | Moderate             |
| 10      | High vigor wheat (30-40 q/ha)      | Coarse loamy | Well drained            | 301-400 mm | 10.0 m-20m         | Moderate             |
| 11      | High vigor wheat (30-40 q/ha)      | Coarse loamy | Well drained            | <300 mm    | 10.0 m-20m         | Moderate             |
| 12      | High vigor wheat (30-40 q/ha)      | Sandy        | Excessively drained     | 301-400 mm | 20m-30m            | Moderate             |
| 13      | High vigor wheat (30-40 q/ha)      | Sandy        | Excessively drained     | <300 mm    | 20m-30.0 m         | Moderate             |
| 14      | Medium vigor wheat (20-30 q/ha)    | Fine loamy   | Well drained            | 301-400 mm | 3m-10m             | Moderate             |
| 15      | Medium vigor wheat (20-30 q/ha)    | Fine loamy   | Moderately well drained | 301-400 mm | 10m-20m            | Moderate             |

|    |                                 |              |                         |            |            |          |
|----|---------------------------------|--------------|-------------------------|------------|------------|----------|
| 16 | Medium vigor wheat (20-30 q/ha) | Coarse Loamy | Well drained            | 301-400 mm | 10m-20m    | Moderate |
| 17 | Medium vigor wheat (20-30 q/ha) | Coarse loamy | Well drained            | <300 mm    | 10m-20m    | Moderate |
| 18 | Medium vigor wheat (20-30 q/ha) | Sandy        | Excessively drained     | 301-400 mm | 10m-20m    | Moderate |
| 19 | Low vigor wheat (<20 q/ha)      | Sandy        | Excessively drained     | 301-400 mm | 1.6m-3.0m  | Moderate |
| 20 | Low vigor wheat (<20 q/ha)      | Fine loamy   | Well drained            | 301-400 mm | 3.0m-10.0m | Moderate |
| 21 | Low vigor wheat (<20 q/ha)      | Fine loamy   | Moderately well drained | 301-400 mm | 3.0m-10.0m | Moderate |
| 22 | Low vigor wheat (<20 q/ha)      | Fine loamy   | Moderately well drained | <300 mm    | 10m-20m    | Moderate |
| 23 | Low vigor wheat (<20 q/ha)      | Coarse loamy | Well drained            | 301-400 mm | 10m-20m    | Moderate |
| 24 | Low vigor wheat (<20 q/ha)      | Coarse loamy | Well drained            | <300 mm    | 10m-20m    | Moderate |
| 25 | Low vigor wheat (<20 q/ha)      | Coarse loamy | Well drained            | 301-400 mm | 3.0m-10.0m | Moderate |
| 26 | Low vigor wheat (<20 q/ha)      | Coarse loamy | Well drained            | 301-400 mm | 3.0m-10.0m | Good     |
| 27 | Low vigor wheat (<20 q/ha)      | Coarse loamy | Well drained            | <300 mm    | 10m-20m    | Moderate |
| 28 | Low vigor wheat (<20 q/ha)      | Sandy        | Excessively drained     | 301-400 mm | 1.6m-3.0m  | Moderate |
| 29 | Low vigor wheat (<20 q/ha)      | Sandy        | Excessively drained     | 301-400 mm | 3m-10m     | Good     |
| 30 | Low vigor wheat (<20 q/ha)      | Sandy        | Excessively drained     | <300 mm    | 10-20      | Moderate |
| 31 | Low vigor wheat (<20 q/ha)      | Sandy        | Excessively drained     | 301-400 mm | 20m-30m    | Moderate |

## 7. REFERENCES

Brown, L.R. 1995. Who Will Feed China? New York: W.W. Norton.

Gadgil, S. and Seshagiri Rao, P.R., 2000. Farming strategies for a variable climate – A challenge. *Current Science* 78: 1203-1215.

Reynolds, C.A. 2000. Estimating crop yields and production by integrating the FAO crop Specific Water Balance model with real-time satellite data and ground base ancillary data. USDA-FAS-PECAD, Rm.6053, 1400 Independence Avenue, Washington, DC.

Parihar, J.S. and Navalgund, R.R., 1992. Crop Production Forecasting in Natural Resources Management-a new perspective (R. L. Karale Ed.); pp 91-107.

Kendall, H.W., and D. Pimentel. 1994. "Constraints on the expansion of the global food supply." *Ambio*, 23: 198-205.

Pimentel, D., C. Harvey, P. Resosudarmo, K. Sinclair, D. Kurz, M. McNair, S. Crist, L. Sphpritz, L. Fitton, R. Saffouri, and R. Blair. 1995. "Environmental and economic costs of soil erosion and conservation benefits." *Science*, 267: 1117-1123.

Pimentel, D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck, and S. Alpert., 1996. "Water resources: agriculture, the environment, and society." *BioScience*, (in press).

RS and NAS, 1992. "The Royal Society and the National Academy of Sciences on Population Growth and Sustainability." *Population and Development Review* 18 (2): 375-378.