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Spatial analysis of potato black scurf disease distribution using GIS and variability of *Rhizoctonia solani* isolates in Central Karakoram National Park Gilgit-Baltistan, Pakistan

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Key words: Black scurf, potato, Distribution, *Rhizoctonia solani*, IDW, Geostatistics GIS, CKNP and Gilgit-Baltistan, Pakistan.

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Abstract

Spatial analysis of black scurf distribution and morphological variability were carried out during the year 2012-13 using geographical information system and geostatistics techniques in four valleys & twenty four villages of CKNP region. During the studied it is showed that among the twenty four village eight villages found > 60 % disease prevalence, thirteen in range of 40 – 60 % and three villages < 40 % while disease incidence and severity were recorded as eight villages > 15 %, thirteen villages 10-15 % and three villages <10 % as well as disease severity; four villages >5, thirteen 3-5 and seven villages in < 5 %. The ranged of disease prevalence (25.0 – 75.0 %), incidence (5.55 – 23.89 %) and severity (1.67 -6.55 %) were recorded. Twenty isolates of *R.solani* were obtained from the infected tubers of potato and characterized their colony growth rate mmd^{-1}, different pH and temperature level. On the basis of colony growth rate (CGR), the isolates were categorized as slow, medium and fast. Twelve isolates (60 % of the total) showed medium growth (10-20 mm-day^{-1}) while eight isolate (40 % of the total) showed fast growth (> 20 mm-day^{-1}). Effects of different temperature and pH levels on CGR of the isolates were assessed. All isolates attained (above 80 mm CGR) at 30 ^{o}C, (70-80 mm CGR) at 25°C and Optimum pH for CGR of isolate were 6.5-7.5 while cluster analysis of twenty isolates were categorized into two main groups i.e. A and B. 70 % of the isolates were classified in cluster A while 30 % in B.

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Introduction

Potato (*Solanum tuberosum* L.) is one of the major cash crops of Gilgit-Baltistan Pakistan. It is grown on an area of 8526 ha with an annual production of 134031 metric ton. It is ranked third in area and production-wise after wheat and maize (Agric statistics 2009). Production of potato has either remained static or declined over the last few years due to biotic and abiotic constraints. Biotic constraints are diseases, insects, pests and weed. The major diseases in potato production are dry rot, wet rot, early blight, verticillium wilt, black scurf and powdery scab. For the last few years, black scurf caused by *Rhizoctonia solani* has been a serious problem in all potato growing valleys of Gilgit-Baltistan (Bhutta *et al.*, 2004). Black scurf is a commonly occurring fungal disease and a serious problem in all potato production agro-ecological zones of Pakistan (Ahmad *et al.*, 1995a) and (Khan *et al.*, 1995). This disease was first time reported by Kuhn during 1858. (Frank 1986). Black scurf is a soil or seed borne disease. Black spots (sclerotia) ranging from 1mm to 10 mm appear on the potato tubers. These spots are difficult to remove by washing and brushing (Wick *et al.*, 2001). It also causes size (reduction) of young (Leach and Webb, 1993; Dillard *et al.,* 1993). More over the affected tubers shows creaking, deformity and pitting leading to poor quality of the produce (Rauf *et al.,* (2007). Detailed information on geographical distribution of a crop disease is important for planning, to develop efficient disease management strategies. GIS application is used to analyze plant disease distribution. For spatial and temporal model analyses have been used in agriculture as well as in the field of plant disease on a variety of scales, from single field to large agricultural area, to assess the connections between host, pathogens and the environment in relation to plant disease epidemics (Nelson *et al.,*1994). Information management system will be playing pivotal role to enhancing agriculture production in the upcoming decades. Because agricultural is naturally spatial and this system organized form information in spatial data base. Biological and physical aspects of agricultural systems produce spatial heterogeneity and as a result, patchiness is the rule in the occurrence and distribution of plant pathogens and disease (Campbell *et al.,* 1990). By application geographic information system (GIS) plant disease management practices can be improved. GIS is a computer base system capable of manipulating, and displaying data by geographic coordinates. GIS program is the best tool for disease forecasting. In case of plant disease management, the data of soil suitability index and rainfall are the important information for disease prevention and control (Star and Estes, 1990). In Gilgit-Baltistan specifically CKNP region scanty information is available on distribution of black scurf of potato. The aim of the current study is to asses spatial distribution (prevalence, incidence & severity) potato black scurf disease and morphological variability of *Rhizoctonia solani* isolates in the valleys of CKNP region of Gilgit-Baltistan. The tools developed in this study are projected for use in a risk evaluation program to improve the integrated management of black scurf disease in potato production area.

Materials and methods

Study area

Central Karakoram National Park CKNP) covers three major districts; Gilgit, Skardu and Ghanche. In 1993; Govt of Pakistan declared CKNP as a national park. Total area cover is over ten thousand km² and encompassing largest glacier; Baltoro, Hispar-Biafo and Siachen of the world outside the Polar Regions whereas the buffer zone (7,400 km²) of CKNP is home to about 97,608 people residing in 230 village settlements. Mixed mountain agriculture is main activity of the locals.

Disease assessment

Spatial analysis of black scurf disease distribution an extensive survey was undertaken in four valleys; that consisted of twenty four villages and one hundred thirty potato fields (Fig 1). The exact villages & sample location was recorded using a handheld GPS (Table 1). Disease distribution including prevalence,

incidence & severity were calculated using following methods described previously (Rauf *et al.*, 2007) and (Munir *et al.*, 1994). For disease prevalence (3-7) farms from each village were selected and calculated on the percentage of farms found infected in a locality survey. For diseases incidence calculated using thirty potato tubers from each farms/spots that were randomly selected while disease severity was assessed on a visual 0-5 rating scale based on percent tuber surface showing disease symptoms. Disease rating was scored as 0 = no disease symptoms on potato tubers; 1 = less than 1% tuber area affected; 2 = 1-10% tuber area affected; 3 = 11-20% tuber area affected; 4 = 21-50% tuber area affected and 5 = 51% or more potato tuber area affected.

$$P\% = \frac{FS}{TF} \times 100 \qquad I\% = \frac{PT}{SPT} \times 100$$

Whereas
P % = Prevalence percentage
FS = Form showing black scurf symptom
TF = Total farm

I % = Incidence percentage
PT = Potato tuber showing black scurf symptom
SPT = Selected potato tuber

$$D.S = \frac{SI}{TR \times MD} \times 100$$

D.S = Disease severity
SI = Sum of all disease rating
TR = Total no. of rating
MD = Maximum disease grade

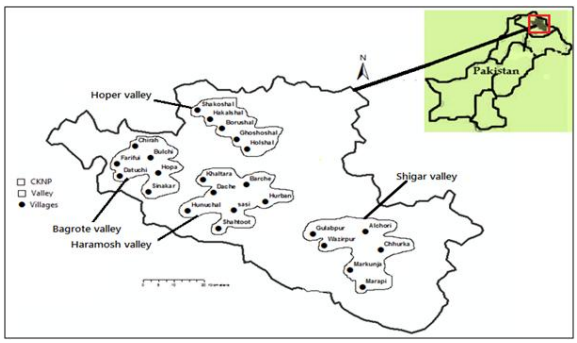

Fig. 1. Location Map of study area valleys/villages of CKNP Gilgit-Baltistan.

Isolation and culture maintenance

Potato tuber showing typical symptoms of black scurf caused by *Rhizoctonia solani* Kuhn were collected. The collected samples were packed in polythene bags and transferred to the laboratory for variability study among the isolates. Twenty isolates of *R. solani*-infecting potato tuber were as RS_1-RS_{20} (Table 2). Theses isolates were surface sterilized by 0.1% mercuric chloride for 2-3 minutes and extensively washed with sterile distilled water. Sclerotial spots on tuber surface were scratched and placed on petri plates containing potato-dextrose-agar. Each isolates were further purified by hyphal tip method and maintain as pure culture. These isolates were stored at 4°C for further characterization.

Morphological characterization of isolates

R.solani isolates were subculture on potato dextrose agar medium in 90 ml Petri plates for comparison morphological variability among the isolates. A 3-4 mm mycelial disc from margins of actively growing 5-day-old fungal colony of each isolate was inoculated in the centre of Petri plate containing PDA. Three replications were maintained for each isolate. Colony growth rate was recorded after 24, 48, 72 and 96 h of incubation at 27±2°C. Radial colony growth $mmday^{-1}$ was determined by using following formula:

$$CGR = \frac{RCG\ 4^{th}\ day}{4}$$

CGR: Colony growth rate
RCG: Radial colony growth

From these isolates which had fastes colony growth were selected for further characterization on different temperature and pH levels.

Characterization of CGR at different temperature and pH

Twenty milliliter of PDA was poured into each of the Petri dish (9 cm diameter). Mycelial discs in 5 mm diameter were cut from the margin of 3-4 days old culture of eight *R. solani* isolates. Three dishes were used for each isolates. After inoculation, the petri dishes were incubated at 10, 15, 20, 25, 30 and 35° C. Similarly the isolates were grown at different pH levels 4.5, 5.5, 6.5, 7.5 and 8.5 of the medium were adjusted by addition of appropriate volume of HCl and NaOH solutions before autoclaving. Three replicates were maintained for recording the data.

Cluster analysis

Morphological data of twenty isolates were analyzed for cluster analysis with the help of computer software SPSS Version 16.01 and STATISTICA 6.0 for Windows 2007.

Geographic information system

A dbf file consisting of data for X and Y coordinate in respect of sampling site location was created. A shape file (vector data) showing the outline of selected valleys, Bagrote, Haramosh, Hoper and Shigar was created in Arc Map 10.1. The dbf file was opened in the project window and in X-field, X-coordinate was selected and in Y-field, Y-coordinate was selected. The Z field was used for disease prevalence incidence and severity of each village. The four valleys shape file was also opened and from the 'surface menu' of Arc Map spatial analyst. Interpolation method employed was IDW and reclassified disease map as prevalence % >60, 40 – 60, < 40, incidence >15, 10 -15 and < 10 %, severity > 5, 3-5 and < 3%.

Results

Black scurf disease prevalence, incidence and severity were carried out during year 2012-13 at harvesting stage of potato. A total of four valleys; twenty four villages; 5-7 villages each valley and 130 field/spot were selected for this purpose. At each village 3-7 farm were randomly selected and disease fields were sampled based on visible symptoms of black scurf on potato tuber. Categorized disease prevalence (> 60, 40-60 & < 40), Incidence (> 15, 10-15 & <10) and severity (> 5, 3-5 & <3). During the studies it is revealed that over all prevalence range (25-75 %), incidence (5.55-23.89 %) and severity (1.67-6.55 %) across the study site.

Table 1. Location of the villages points in the study area of CKNP.

S/No	Valley	Villages	Latitude	Longitude
1	Bagrote valley	Saniker	35° 57' 27.7842"	74° 30' 59.3346"
2		Datuchi	36° 0'6.17"	74°32'10.04"
3		Hopay	35° 58' 34.122"	74° 31' 54.0804"
4		Bulchi	36° 1' 15.6684"	74° 32' 38.9898"
5		Furfu	36° 0' 25.2894"	74° 32' 35.5164"
6		Chirah	36° 1' 29.6142"	74° 33' 23.31"
7	Haramosh valley	Sasi	35° 50' 14.5788"	74° 44' 29.5584"
8		Hurban	35° 50' 10.86"	74° 45' 43.542"
9		Shahtoot	35° 48' 34.8984"	74° 44' 25.8108"
10		Honuchal	35° 50' 19.7484"	74° 41' 59.6112"
11		Dache	35° 53' 8.9082"	74° 45' 10.7418"
12		Barchi	35° 54' 35.067"	74° 46' 46.6638"
13		Khaltara	35° 54' 45.3378"	74° 43' 1.1598"
14	Hoper valley	Shakoshal	36° 14' 46.485"	74° 44' 18.6792"
15		Halkalshal	36° 14' 4.7796"	74° 44' 43.4898"
16		Borushal	36° 13' 27.0408"	74° 45' 3.8118"
17		Gashoshal	36° 12' 40.5864"	74° 45' 21.2328"
18		Holshal	36° 11' 57.0366"	74° 45' 21.2328"
19	Shigar valley	Marapi	35° 23' 43.2384"	75° 44' 33"
20		Murkunja	35° 26' 16.89"	75° 43' 43.9386"
21		Chhurka	35° 29' 1.0782"	74° 41' 35.5698"
22		Alchori	35° 31' 53.0286"	75° 37' 50.2422"
23		Gulabpur	35° 33' 30.1098"	75° 28' 45.4512"
24		Wazirpur	35° 30' 4.5606"	75° 35' 37.716"

Disease prevalence

Village wise disease prevalence in Bagrote valley a total of six villages were selected among these two villages (Saniker & Furfu) having disease prevalence >60 disease while remaining four villages (Datuchi, Bulchi, Chirah & Hopay) disease prevalence were recorded in the range of 40-60 % . In Haramosh valley total seven villages were selected, among these

villages one villages (Barchi) > 60, four villages (Hurban, Shahtoot, Dache & Khaltara) 40-60 and two villages (Sasi & Honuchal) < 40 % disease prevalence were recorded while in the Hoper valley five villages were selected and disease prevalence found as two village (Borushal & Halkalshal) > 60 while the other three villages (Holshal, Gashoshal Shakoshal) in the range of 40-60 %. In Shigar valley six villages were selected only one village (Markunja) in < 40 % disease prevalence while three villages (Marapi, Gulabpur & Wazirpur) were in the range of 40-60 % and two villages (Chhurka & Alchori) > 60 % prevalence were recorded (Fig 3). Minimum maximum, and mean disease prevalence in Bagrote valley (50.0, 75.0 & 63.09), Haramosh (25.0, 66.66 & 44.46), Hoper (40.0, 71.42 & 61.10), Shigar (33.33, 75.0 & 57.81) were recorded respectively (Fig 4).

Disease incidence

In Bagrote valley village Saniker, Bulchi and Furfu (> 15), Datuchi and Chirah (10-15) and Hopay village (< 10) disease incidence was recorded while in Haramosh valley all villages fall in the range of (10-15) disease incidence except Hurban village (< 10). In Hoper valley village Holshal and Halkalshal (> 15), village Gashoshal, Borushal and Shakoshal (10-15) disease incidence were found as well as in Shigar valley village (Marapi, Chhurka and Alchori (> 15), Gulabpur and Wazirpur (10-15) and Murkunja < 10 disease incidence were recorded (Fig 5) while valley wise minimum, maximum and mean disease incidence were recorded as Bagrote valley (8.89, 17.33 & 12.91), Haramosh valley (5.55, 13.33 & 11.84), Hoper valley (11.67, 18.89 & 14.58) and Shigar valley (6.33, 23.89 & 14.64) (Fig 6).

Table 2. Morphological variability of f *Rhizoctonia solani* isolates on PDA from different potato growing villages of CKNP Region Gilgit-Baltistan.

	Colony Growth Rate				
Isolates	1st day	2nd day	3rd day	4th day	CGR (mmd^{-1})
RS_1	3.50_{L}	12.76^{L}	28.30_{Q}	58.20_{K}	14.55
RS_2	8.56_{J}	28.23^{G}	54.18_{E}	84.50_{C}	21.12
RS_3	10.26_{G}	29.23^{F}	55.10_{D}	85.36_{B}	21.34
RS_4	12.13_{C}	33.26^{C}	56.16_{B}	86.20_{A}	21.55
RS_5	10.20_{G}	34.16^{A}	54.20_{E}	84.36_{C}	21.09
RS_6	3.60_{L}	13.23^{K}	29.63_{O}	58.33_{K}	14.58
RS_7	4.20_{K}	12.46^{L}	32.73_{N}	52.50_{M}	13.12
RS_8	4.00_{K}	13.40^{K}	34.56_{M}	56.10_{L}	14.02
RS_9	2.93_{M}	11.60^{M}	28.93_{P}	49.26_{N}	12.31
RS_{10}	10.53_{EF}	31.34^{D}	57.23_{A}	84.36_{C}	21.09
RS_{11}	9.70_{H}	26.76^{I}	49.63_{J}	72.56_{H}	18.14
RS_{12}	11.13_{D}	29.63^{E}	53.76_{F}	82.10_{D}	20.52
RS_{13}	8.40_{J}	25.56^{J}	46.70_{L}	64.43_{J}	16.10
RS_{14}	9.16_{I}	27.23^{H}	50.20I	78.33_{F}	19.58
RS_{15}	12.40_{B}	33.70^{B}	56.40_{B}	85.03_{B}	21.25
RS_{16}	12.00_{C}	33.90^{AB}	55.70_{C}	84.20_{C}	21.05
RS_{17}	10.60_{E}	29.46^{EF}	47.43_{K}	75.86_{G}	18.96
RS_{18}	13.20_{A}	34.20^{A}	56.23_{B}	79.93_{E}	19.98
RS_{19}	10.30_{FG}	27.30^{H}	52.53_{H}	70.13_{I}	17.53
RS_{20}	9.93_{H}	28.53^{G}	53.23_{G}	72.20_{H}	18.05
CVC	0.26	0.37	0.41	0.41	

Values within columns having common letter do not differ significantly LSD (P =0.05).

Table 3. *Rhizoctonia solani* isolates categorized into three classes on the basis of radial colony growth mmd-

S/No	Category		Number	Isolates	Frequency %
1	Low	< 10	0		0
2	Medium	10-20	12	RS_1, RS_6, RS_7, RS_8, RS_9, RS_{11}, RS_{13}, RS_{14}, RS_{17}, RS_{18}, RS_{19}, RS_{20}	60
3	High	>20	8	RS_2, RS_3, RS_4, RS_5, RS_{10}, RS_{12}, RS_{15}, RS_{16}	40

Disease severity

Village wise disease severity was recorded as in Bagrote valley Furfu village category I, Saniker, Datuchi and Bulchi in category II; Chirah and Hopay in category III. In Haramosh valley, village Khaltara category I, Sasi, Shahtoot, Dache; Barchi in category II; Hurban and Honuchal category III while in Hoper valley one village in category I, two villages in category II and two villages in category III. In Shigar valley Gulabpur village category I, four villages in category II and Murkunja village fall in category I on basis of disease severity (Fig 7) while valley wise minimum, maximum and mean disease severity were recorded as Bagrote valley (2.0, 5.22 & 3.44), Haramosh valley (2.0, 5.11 & 3.60), Hoper valley (2.33, 5.83 & 4.02) and Shigar valley (1.67, 6.55 & 3.93) (Fig 8).

Table 4. Colony mycelial growth rate (mm) of eight isolate of *Rhizoctonia solani* on PDA at different pH level.

Isolate	pH 4.5	PH 5.5	pH 6.5	pH 7.5	pH 8.5
RS_2	26.63_{E}	34.56_{F}	43.47_{D}	46.28_{D}	40.60_{D}
RS_3	34.47_{D}	54.60_{C}	85.34_{A}	86.44_{AB}	65.23_{A}
RS_4	40.10_{AB}	58.52_{AB}	85.55_{A}	87.18_{A}	62.26_{B}
RS_5	38.28_{C}	59.28_{A}	84.0_{B}	86.38_{AB}	61.37_{B}
RS_{10}	40.92_{A}	57.59_{B}	84.22_{B}	86.11_{AB}	60.72_{B}
RS_{12}	39.32_{BC}	50.43_{D}	80.04_{C}	81.44_{C}	54.46_{C}
RS_{15}	39.58_{B}	48.89_{DE}	85.09_{A}	85.85_{B}	61.06_{B}
RS_{16}	39.14_{BC}	47.70_{E}	84.10_{B}	85.67_{B}	60.00_{B}
St.Err	0.57	0.75	0.36	0.53	1.20

LSD is the least significant difference at 5 % (P =0.05) Values within a column having common letter do not differ statistically.

Morphological variability

Twenty isolates of *R.solani* were selected for their morphological variability and majority of isolates showed colony growth rate in the range of 10-20 mm/day while the lowest colony growth was observed in isolates RS_1. Higher growth rate were observed in isolates; including RS_2, RS_3, RS_4, RS_5, RS_{10}, RS_{12}, Rs_{15} and RS_{16} (Table 1). Based on CGR variability isolates were categorized into three groups. On the basis of colony growth rate, the isolates were grouped as slow, medium and fast colony growth rate < 10, 10-20 and > 20 mmd^{-1} respectively. Non of the isolates exhibited slow growth rate while the twelve isolates showed medium growth rate and rest of isolates showed fast growth (Table 2).

Mycelial growth at different temperature

All eight isolates were growing at temperature range of 10-35 °C (Fig 9). The behaviour of colony growth of all isolates more or less same. Maximum colony growth of all isolates on PDA was at 30 °C which was followed by 25 °C. However the growth of isolates was drastically reduced below 15 °C. It was recorded that at 30 °C all isolates attained the maximum growth (above 80 m m) while at 25 °C ranges of growth between 75-80 mm were observed.

Effect of pH on colony growth

Variation of growth among the eight isolates was observed. All tested isolates of *R. solani* grew on PDA medium at all pH within the range of 4.5 -8.5 while the maximum colony growth was observed at pH 7.5

except RS_2 where best growth was observed in isolate of RS-3. Growth of isolates at pH 6.5 & 8.5 followed more or similar pattern whereas at 5.5 and 4.5 significantly lowest growth was noted (Table 4).

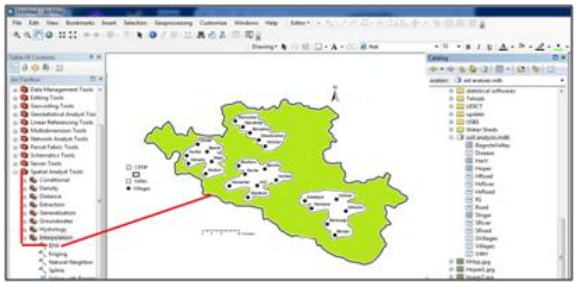

Fig. 2. GIS Interpolation IDW for spatial analysis of disease distribution.

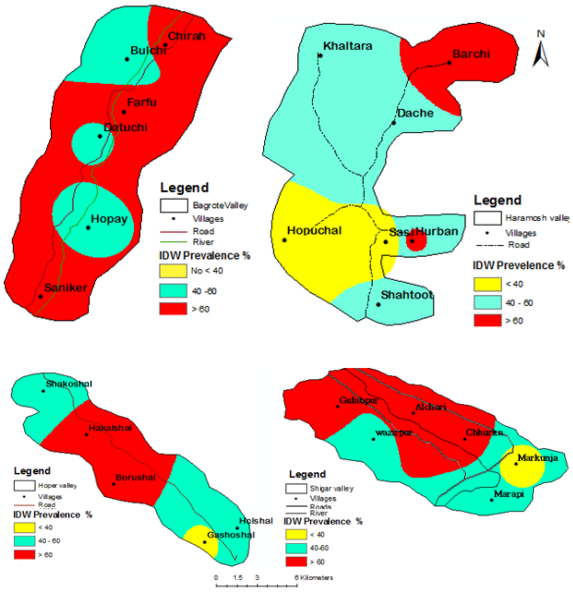

Fig. 3. Spatial analysis of black scurf prevalence in Bagrote, Haramosh, Hoper and Shigar valley.

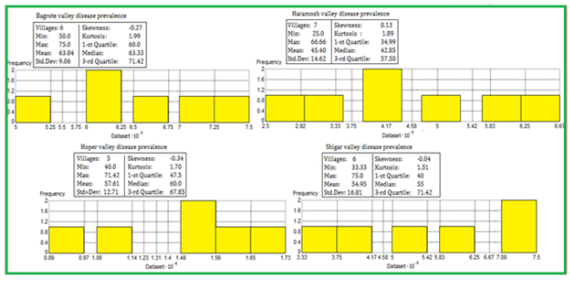

Fig. 4. Histogram and geostatistics of black scurf prevalence in Bagrote, Haramosh, Hoper and Shigar valley.

Cluster analysis

The cluster analysis of twenty isolates of *R. solani* of CGR mmd^{-1} was done to find out variability between these isolates. The dendrogram based on dissimilarity matrix showed two main groups A & B (Fig 10). The result showed that 14 isolates were present in group A, remaining in group B. Group A, further classified into a-1 contains 9 isolate and a-2, having 5 isolate. In cluster B further classified, b-1 contains 4 isolates, b-2 and b-3 having one isolates.

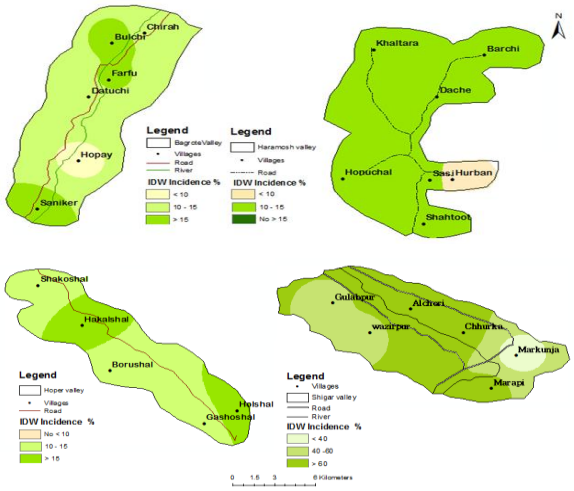

Fig. 5. Spatial analysis of black scurf incidence in Bagrote, Haramosh, Hoper and Shigar valley.

Discussion

GIS and Black scurf disease distribution

Agriculture in Gilgit-Baltistan transforming from subsistence level to commercial enterprise especially for potato production which is one of the major agricultural crop. This area is considered rich basket of producing quality seed potato. Unfortunately, last 10-15 years potato crop faced different pathological problems. Among these black scurf is one of the major biotic constraints but there are no published reports in Gilgit-Baltistan especially CKNP region regarding spatial distribution of black scurf of potato. In this regard four valleys, twenty four villages and one thirty fields were selected because most of the farmers were growing potato as major cash crop in these areas. During the surveys and interviews with the farmers it was revealed that black scurf was prevalent the potato growing valleys of CKNP region. The distribution varied from valley to valley, even from village to village within same valley. This is due to indiscriminate flow of sub standard diseased seed, weak internal quarantine system, mono cropping, lack of crop rotation, poor crop husbandry. Our

information were in agreements with Hooker, 1981 who reported many causes of high prevalence, incidence and severity of black scurf disease which include favourable climatic conditions, mono-cropping, chiefly growing susceptible varieties to black scurf disease of potato, lack of crop rotations, unsafe seed flow and lack of quarantine procedures for the disease. Bhutta *et al.,* (2003) reported that Cardinal and Desire are the two major potato varieties grown in Gilgit-Baltistan followed by Ultimus and Diamant. Ahmad *et al.*,1995c also reported that Desire is the most susceptible to black scurf disease of potato. Diamant and Patronse variety of potato is highly susceptible to particular disease (Zanoni 1991). Desire, Diamant, Cleopatra and Ultimus are susceptible to black scurf disease Rauf *et al.* (2007). Most fungus-like disease causing agents of potato survive in or on infected potato tubers. Potato seed tubers are well thought-out the main agent of dispersal of potato pathogens from one region to another within a country or among different countries and continents (Stevenson *et al.,* 2001). It is tolerated to a greater degree. According to the CKNP farmers all the potato seeds brought from other regions of country did not qualified the visual examination (interview information with farmers). The results of this study recommend that visual examination procedure should be implemented and enforce to strengthen Gilgitian regulations.

GIS was introduced to forecast the disease distribution in the future and also to study the correlation between topography, land use, water network, soil suitability and rain fall data base (Sirirat & Vicharm, 2001). GIS has been used most extensively for mapping distribution of the disease or the specific genotype of plant pathogen (Nelson *et al.,* 1994). Spatial pattern and hotspot analysis over large region has prompted the application of the GIS and geostatistics that can be use to analyses and manage plant disease information data. Spatial pattern provides quantative information on population dynamic, aid in the design of epidemiological studies and sampling programme for disease or pathogen monitoring (Idris *et al.,* 2009). Plant disease results from the interaction of host and the pathogen with the environment. Spatial analysis and GIS is natural partner for the analysis and modeling of environmental data because data from both an organisms and its environment are often spatial in nature (Cressie and Verhoof, 1993).

Morphological of variability of isolates

Our current study showed that a significant morphological variability exist among the isolates which is agreement of Gupta (1992), Sunder *et al.,* (2003), Tarlochan *et al.*, (2008) who reported morphological variability among the isolates of *R.solani*. The current study showed that mycelial growth differs to a great extent depending on temperature and pH levels. The results indicated that the temperature (25-30 ^{o}C) and pH (6.5-7.5) supported maximum colony growth. The earlier studies reported that the most favorable temperatures for the colony growth of *R solani* isolates is between 22 and 25^{o}C (Chand & Logan 1993, Gosawami *et al.,* 2011 studied behaviour of isolates of *R.solani* on different temperature and pH regim on potato dextrose agar. He observed that the suitable temperature; 25-30 ^{o}C and pH 6-7 for maximum mycelial growth and sclerotial production. Similar results were also reported by Band *et al.,* (1996) and Nelson *et al.,* (1996). Kaminski and Verma (1985) reported that isolates of *R. Solani* are variable on the basis of growth rate and sclerotia formation at selected temperature. Kobayashi, 1985 stated there is a direct relationship between colony growth of *R. solani* on pH while Chang (1985) found that both mycelial growth and sclerotial formation of *R. solani* was maximal at pH 7. Sharma & Chowdhury 1984 found that low incidence of *R. solani* at neutral pH than in those with pH 7.4 -8.5. Mercelo and Vega, (1988) observed that optimum condition for *R. solani* was in pH 6-6.5. These variable results might be due to existence of variability among the isolates of *R. solani* which supported the findings of the present investigation.

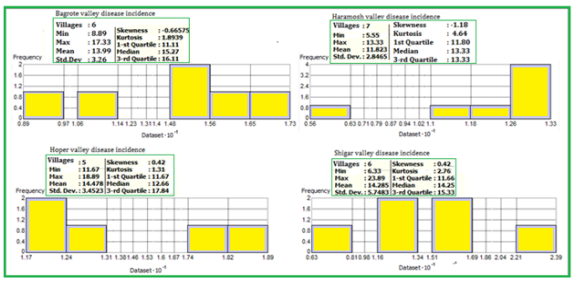

Fig. 6. Histogram and geostatistics of black scurf incidence in Bagrote, Haramosh, Hoper and Shigar valley.

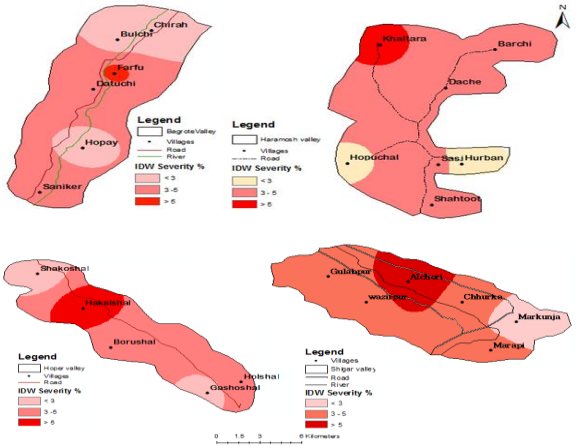

Fig. 7. Spatial analysis of Black scurf severity in Bagrote, Haramosh, Hoper and Shigar valley.

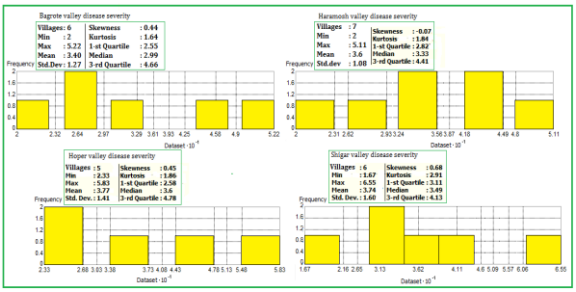

Fig. 8. Histogram and geostatistics of black scurf severity in Bagrote, Haramosh, Hoper and Shigar valley.

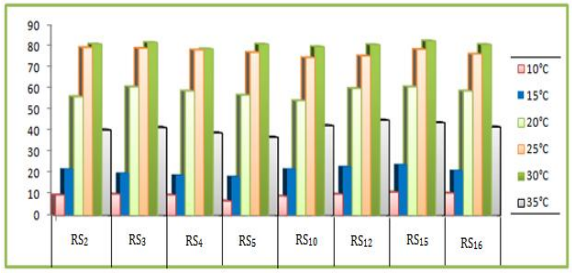

Fig. 9. Colony mycelial growth rate (mm) of eight isolate of *Rhizoctonia solani* on PDA at different temperature level.

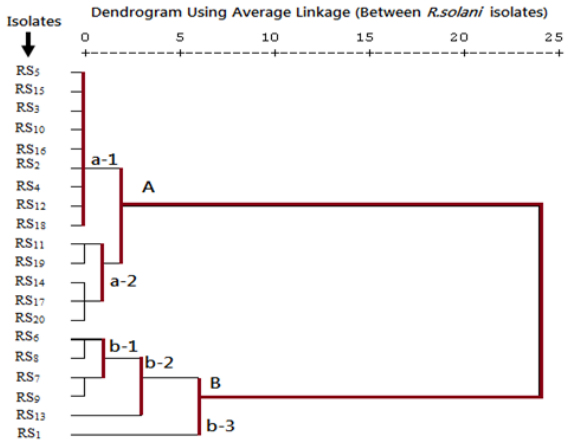

Fig. 10. Morphological variability of the isolates of *R. solani* on the basis CGR (mm/day)

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Abbreviation: CKNP: Central Karakoram National Park; GIS: Geographical information system: CGR: Colony growth rate; IDW: Inverse distance weight; PDA: Potato dextrose agar.