INTRODUCTION

Potato is the third most important food crop in the world after rice and wheat which is consumed by over a billion people globally. At present, India produces 40 mt of potato from an area of approximately 1.83 m ha which is likely to touch 69 m t by 2030 (Vision 2030) provided biotic stresses, especially late blight (LB) are kept under check. Late blight caused by Phytophthora infestans is often regarded as the most important disease of potato globally. Over the past two to three decades there has been an increase in the infection potential of P. infestans in almost all potato growing areas worldwide due to development of new population and changes in genetic diversity of the pathogen (Hannukkala et al., 2007). Globally, late blight carries multiple costs, including complete crop failures, economic losses due to decreased yield, and fungicide applications with a potentially negative impact on human health and the environment (Forbes, 2010). Worldwide potato crop losses due to late blight have been estimated at €12 billion (Haverkort et al., 2009). In India, severity of late blight varies from region to region, being more severe in temperate highlands than in the sub-tropical plains.
with an average of 15% crop losses annually (Collins, 2000). Forecasting can greatly help potato farmers to take prophylactic sprays and prevent or delay appearance of the disease and thus reduce the crop losses. ‘JHULSACAST’- a computerized late blight forecasting model has been developed to predict first appearance of late blight in sub-tropical plains (Singh et al., 2000). This model has worked very well and is being used widely to forecast appearance of late blight in Punjab and western Uttar Pradesh to enable farmers to take up prophylactic sprays of fungicide in time to protect their crop from late blight (Arora et al., 2012).

In potato cultivation, potato seed is most expensive input accounting for 40 to 50% of the production cost. Since the eastern, north-eastern, Deccan and south western parts of the country are not suitable for quality seed production barring few locations, the farmers of these areas have no option but to buy the seed potato from northern India. The high hills of Himachal Pradesh, Indo-Gangetic plains of Punjab, Haryana, north-western part of Uttar Pradesh, and Bihar are suitable for nucleus and breeder seed production. However, Punjab and western Uttar Pradesh are two major states which supply quality potato seed to rest of the country. In case of climate change scenario, the temperature change is likely to affect the late blight outbreak in Punjab and western Uttar Pradesh, thus affecting the potato seed production. Keeping this in mind, a study was initiated which was aimed at studying the impact of climate change on late blight in Punjab and western Uttar Pradesh using JHULSACAST.

MATERIALS AND METHODS

In the present study, JHULSACAST model was used to work out the effect of climate change on potato late blight outbreak, duration of favourable period and disease severity. The JHULSACAST model has been developed and calibrated for western Uttar Pradesh and Punjab (Singh et al., 2000; Arora et al., 2012). The model requires hourly temperature data (°C), relative humidity (RH%) and daily rain (mm) data as input. JHULSACAST states that if 7 day moving RH of ≥85% for a period of ≥60 hours and 7 day moving congenial temperature (7.2 to 26.6 °C) ≥120 hours conditions prevail for 7-consecutive days, late blight would appear within 10 days in western Uttar Pradesh. The modified version of JHULSACAST model for Punjab states that if 7 day moving RH ≥85% for a period ≥90 hours and 7 day moving congenial temperature (7.2 to 26.6°C) ≥105 hours conditions prevail for 7-consecutive days, late blight would appear within 10 days in Punjab.

The model was run for baseline scenario (year 2000) and future climate scenarios (years 2020 and 2055). IMD district normals of 1971-2000 were used for baseline scenario (year 2000) and for future climate scenarios of the years 2020 and 2055 A1FI scenario of temperature (SRES A1FI pathway) was used. As per the IPCC 4th Assessment report, an increase in temperature ranging from 0.78 °C during September, October, November to 1.17°C during December, January, February is expected under A1FI scenario by 2020 in South Asia. These changes are expected to aggravate and range from 1.71°C during June, July, August to 3.16°C during December, January, February, i.e. the main potato growing season in 2055. It is not possible to predict the daily humidity in years 2020 and 2055 during cropping period, therefore, we assumed that 85% and 90% RH would start from a week of emergence of the crop in western Uttar Pradesh and Punjab respectively and proceed with 10 days intervals after the setting of required RH. Thus, the model results are the outcome of the effect of temperature input. To estimate the number of sprays required in seed crop, the
daily severity values were calculated on the basis of decision support system developed for western Uttar Pradesh and Punjab (http://cpri.ernet.in). The accumulation of the severity was started as soon as the prediction of first appearance occurred. The number of sprays needed in seed crop was calculated by dividing total accumulated severity by 180 for contact fungicides. The value of divisor 180 was derived empirically.

**Study areas**

The study was done for entire Punjab state and 23 contiguous districts of western Uttar Pradesh (Fig. 1). The JHULSACAST model was run on available weather data for 13 districts of Punjab and 21 districts of western Uttar Pradesh, as given in tables 1 and 2, and the results of these districts were extended to the entire study area employing kriging technique.

**Weather data**

Indian Meteorological Department’s district normals of years 1971 to 2000 of 13 districts of Punjab (Amritsar, Bhatinda, Faridkot, Fatehgarh, Firozpur, Gurdaspur, Hoshiarpur, Ludhiana, Mansa, Moga, Muktsar, Patiala and Sangrur) and 21 districts of western Uttar Pradesh (Agra, Aligarh, Badaun, Baghpat, Bareilly, Bijnor, Etah, Farrukhabad, Firozabad, Gautam Buddha Nagar, Ghaziabad, Hathras, Jyotiba Phule Nagar, Mainpuri, Mathura, Moradabad, Muzaffarnagar, Pilibhit, Rampur, Saharanpur and Shahjahanpur) were used for baseline scenario in the present study. For generation of scenarios for 2020 and 2055, projected changes in surface air temperature for sub-regions of the Asia under SRES A1FI pathway based on the Fourth Assessment Report (AR4) Atmosphere-Ocean General Circulation Models (AOGCMs) were added on the baseline data (IPCC 2007). The temperature values added were +0.78°C during September, October and November and +1.18°C during December, January and February in 2020. Whereas, the temperature added on baseline for 2055 were +2.41°C during September, October and November and +3.16 during December, January and February. Hourly temperature data has been derived from daily maximum and minimum temperature data employing the method suggested by Carla et al. (2000)

**Kriging**

GIS maps of western Uttar Pradesh and Punjab were developed using remote sensing and GIS software ‘Geomatica’. For spatial analysis, two separate images of 500 m pixel size were created for state of Punjab and 21 contiguous districts of western Uttar Pradesh. These images were used for generation of GIS maps. Point layers of 13 districts of Punjab and 23 districts of western Uttar Pradesh were created using their geographical locations. The attribute data of each district containing LB appearance, LB favourable days and delay in LB appearance in Punjab in different scenarios were geo-statistically interpolated using kriging technique to produce surface layers of the attributes. For kriging, spherical variogram was chosen for interpolation of the point data. The modeling for % change in containing LB appearance, LB favourable days and delay in LB appearance in Punjab in years 2000, 2020 and 2055 were done in EASIPACE-a image processing software. GIS software was also used to estimate the area falling under different class of attributes. The kriging was done for Punjab and western Uttar Pradesh separately.

Potato in Punjab and western Uttar Pradesh is planted as early as in the end of September and planting continues till the mid December. Thus, the harvesting is also extended till the month of March. Therefore,
Climate change impact on late blight outbreak

<table>
<thead>
<tr>
<th>Punjab</th>
<th>S.No.</th>
<th>Name of the district</th>
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<tbody>
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</tr>
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</tr>
<tr>
<td>8</td>
<td>Ludhiana</td>
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</tr>
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</tr>
<tr>
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<td></td>
</tr>
<tr>
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<td>Faridkot</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Moga</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Bathinda</td>
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<tr>
<td>14</td>
<td>Barnala/Sangrur</td>
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</tr>
<tr>
<td>15</td>
<td>Fatehgarh Sahib</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Mansa</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Patiala</td>
<td></td>
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<table>
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</tr>
<tr>
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<td>Bijnor</td>
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</tr>
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<td>6</td>
<td>Ghaziabad</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Jyotiba Phule Nagar</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Moradabad</td>
<td></td>
</tr>
<tr>
<td>9</td>
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<td>Bareilly</td>
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<td>Mainpuri</td>
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</tr>
<tr>
<td>21</td>
<td>Farrukhabad</td>
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</tr>
<tr>
<td>22</td>
<td>Shahjahanpur</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Pilibhit</td>
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</tr>
</tbody>
</table>

Fig. 1. Study areas of Punjab and western Uttar Pradesh

This study was done for a period ranging from 1 October to 31 March, i.e. crop growth period the potato crop growth period.

The optimum time of planting potato crop for seed purpose is the first week of October in Punjab while it is mid October.
for western Uttar Pradesh. The crop normally takes about 15 days to complete emergence and is harvested about 90 days after planting. Therefore, for working out the number of fungicide sprays required in seed crop, the total growth period from emergence to 10 days before harvesting i.e. total 65 days, is considered starting from 20 October in Punjab and 30 October in western Uttar Pradesh.

RESULTS AND DISCUSSION

Outbreak of late blight

**Punjab:** In Punjab, appearance of late blight (LB) was witnessed on 13 October (**Table 1**) in northern districts (Fatehgarh, Firozpur, Gurdaspur and Hoshiarpur) and latest by 24 October in southern district (Mansa) under the baseline scenario (2000). In Pathankot, Gurdaspur, Amritsar, Hoshiarpur, Rupnagar, parts of Kapurthala and Jalandhar districts, which constitute 38.9% of the geographical area, the 1st appearance of late blight was observed during 13 to 16 October whereas in Fazilka, Muktsar, Faridkot, Bathinda, Barnala, Sangrur and parts of Patiala (**Table 1**), which constitute 37.8% of the total geographical area of Punjab, the disease appeared during 21 to 25 October under the baseline scenario (**Fig. 2**). In rest of the state (23.3% of the total geographical area), late blight appeared during 17 to 20 October under the baseline scenario. This variance in disease appearance is ascribed to variations in climate, especially temperature. However, when future climate scenario was considered for 2020, late blight appearance was delayed by 0 to 6 days depending on the geographical locations in the state. The model predicted 0 to 3 days delay in 1st appearance in north eastern, western and some parts of central Punjab, comprising 60% of the area. In other parts, late blight appeared 4 to 6 days later than the reference year 2000. This could be due to projected high temperature in year 2020 (1.08°C) leading to delayed accumulation of 7

Table 1. Late blight appearance, duration of favourable period and number of sprays required at different locations in Punjab in years 2000, 2020 and 2055.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Location</th>
<th>Late blight appearance</th>
<th>Delay in LB appearance over 2000</th>
<th>Interim late blight free days in 2000</th>
<th>Total late blight favourable days</th>
<th>Change in late blight favourable days over 2000</th>
<th>Max. no. of sprays required for controlling late blight after appearance</th>
<th>Change in no. of sprays</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Amritsar</td>
<td>14 Oct.</td>
<td>7</td>
<td>14</td>
<td>82</td>
<td>86</td>
<td>10 67</td>
<td>5</td>
<td>6 9 1 4</td>
</tr>
<tr>
<td>2. Bathinda</td>
<td>24 Oct.</td>
<td>4</td>
<td>13</td>
<td>65</td>
<td>93</td>
<td>33 50</td>
<td>7</td>
<td>8 8 1 1</td>
</tr>
<tr>
<td>3. Faridkot</td>
<td>23 Oct.</td>
<td>3</td>
<td>14</td>
<td>67</td>
<td>92</td>
<td>34 52</td>
<td>7</td>
<td>8 8 1 1</td>
</tr>
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<td>4. Fatehgarh</td>
<td>13 Oct.</td>
<td>0</td>
<td>13</td>
<td>28</td>
<td>140</td>
<td>28 15</td>
<td>9</td>
<td>10 10 1 1</td>
</tr>
<tr>
<td>5. Firozpur</td>
<td>13 Oct.</td>
<td>0</td>
<td>12</td>
<td>72</td>
<td>97</td>
<td>42 59</td>
<td>6</td>
<td>9 9 3 3</td>
</tr>
<tr>
<td>6. Gurdaspur</td>
<td>13 Oct.</td>
<td>0</td>
<td>13</td>
<td>81</td>
<td>88</td>
<td>19 67</td>
<td>6</td>
<td>9 9 3 3</td>
</tr>
<tr>
<td>7. Hoshiarpur</td>
<td>13 Oct.</td>
<td>3</td>
<td>13</td>
<td>79</td>
<td>90</td>
<td>22 65</td>
<td>5</td>
<td>6 9 1 4</td>
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<td>8. Ludhiana</td>
<td>17 Oct.</td>
<td>7</td>
<td>9</td>
<td>40</td>
<td>107</td>
<td>50 42</td>
<td>8</td>
<td>9 9 1 1</td>
</tr>
<tr>
<td>9. Mansa</td>
<td>24 Oct.</td>
<td>5</td>
<td>15</td>
<td>39</td>
<td>119</td>
<td>33 19</td>
<td>8</td>
<td>9 8 1 0</td>
</tr>
<tr>
<td>10. Moga</td>
<td>23 Oct.</td>
<td>3</td>
<td>14</td>
<td>36</td>
<td>123</td>
<td>29 7</td>
<td>7</td>
<td>8 8 1 1</td>
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<tr>
<td>11. Muktsar</td>
<td>23 Oct.</td>
<td>3</td>
<td>14</td>
<td>67</td>
<td>92</td>
<td>34 52</td>
<td>7</td>
<td>8 8 1 1</td>
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<td>12. Patiala</td>
<td>19 Oct.</td>
<td>5</td>
<td>13</td>
<td>24</td>
<td>138</td>
<td>19 11</td>
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<td>9 9 0 0</td>
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<td>13. Sangrur</td>
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<td>42</td>
<td>118</td>
<td>38 25</td>
<td>8</td>
<td>9 9 1 1</td>
</tr>
</tbody>
</table>
Climate change impact on late blight outbreak

Fig. 2. Distribution of LB appearance, LB favourable days and delay in LB appearance in Punjab in years 2000, 2020 and 2055.

<table>
<thead>
<tr>
<th>Maximum no. of sprays required in 2000</th>
<th>Earliest late blight appearance in 2000</th>
<th>Late blight favourable days in 2000</th>
<th>Change in no. of sprays in 2020 over 2000</th>
<th>Change in no. of sprays in 2055 over 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>10–20</td>
<td>10–20</td>
<td>+1</td>
<td>+2</td>
</tr>
<tr>
<td>11–125</td>
<td>21–30</td>
<td>31–40</td>
<td>+1</td>
<td>+2</td>
</tr>
<tr>
<td>126–140</td>
<td></td>
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</tr>
</tbody>
</table>

Increase in late blight favourable days in 2020

Increase in late blight favourable days in 2055

Delay in late blight appearance in 2055 (days)
day moving sum of temperature between 7.2 to 26.6°C. The model predicted further delay in late blight appearance by 12 to 14 days in year 2055 over baseline. Barring some patches in northern, eastern and western Punjab where late blight appearance delayed by 12 days and some parts of central and southern Punjab where a 14 days delay was observed, the model predicted 13 days delay in rest of Punjab (69% area) in year 2055 from the baseline year 2000 (Fig. 2).

Uttar Pradesh: Prevailing temperatures in Saharanpur and Pilibhit districts were low as compared to rest of the western Uttar Pradesh that led to an early onset of late blight outbreak (13 to 17 October) in the year 2000. As we moved towards south i.e. Mathura, Agra, Firozabad and Mainpuri, the first appearance of late blight got delayed and the model predicted late blight appearance not before 2 to 5 November in these districts. Under favourable moisture conditions, 39% of the geographical area of western Uttar Pradesh remained late blight free till end of October (28 October to 01 November) and 27.6% area till 23 to 27 October (Table 2).

A likely increase in temperature by the year 2020 caused delay in appearance of late blight up to 8 days. Although the disease appeared almost during the same time (0

### Table 2. Late blight appearance, duration of favourable period and number of sprays required at different locations in western Uttar Pradesh in years 2000, 2020 and 2055.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Location</th>
<th>Late blight appearance</th>
<th>Delay in LB appearance over 2000</th>
<th>Total late blight favourable days</th>
<th>Change in late blight favourable days over 2000</th>
<th>Max. no. of Sprays required for controlling late blight after appearance</th>
<th>Change in no. of sprays</th>
</tr>
</thead>
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<td>-29</td>
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<td>100</td>
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<tr>
<td>5</td>
<td>Baghat</td>
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<td>-8</td>
<td>-30</td>
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to 2 days delay) in year 2020 in parts of Muzaffarnagar, Meerut and Bijnor, it was delayed by up to 7 to 8 days in Pilibhit, parts of Rampur, Bareilly and Shahjahanpur. Delay (3 to 6 days) in late blight appearance in rest of the western Uttar Pradesh (83.6% area) has been predicted. With further increase in temperature in year 2055 (Table 2) late blight appearance is projected to be delayed from 10 to 21 days over the baseline year 2000. In majority of the area (52%) which lies in central part, the late blight appearance could be delayed by 15 to 18 days. However, in north eastern pocket (24% area), the delay could be as much as 19 to 21 days.

Late blight favourable days

Out of the total 182 days available for potato growth in Punjab, 80 to 140 days were favourable for late blight as far as the congeniality of temperature was concerned. The least number of late blight favourable days (80-95) in baseline year 2000 were in Pathankot, Gurdaspur, Amritsar, Firozpur, Muktsar, parts of Faridkot, Hoshiarpur, Jalandhar and Kapurthala districts while Patiala, Fatehgarh Sahib, Mohali and parts of Rupnagar districts had the highest number (126-140) of late blight favourable days. In general, blight favourable days during the potato crop growth period increased as we move from north and western parts to eastern parts (Fig. 2).

Ambient temperature in the baseline scenario remains suboptimal (<7.2°C) for quite some time in the state of Punjab for late blight appearance. But in the climate change scenario, the temperatures are likely to go up which will affect late blight favourable days. Consequently, in year 2020, late blight favourable days increased from 10 to 40 days over the baseline (year 2000) depending on the location in Punjab. The increase in late blight favourable days would be less (10 to 20 days) in the case of Pathankot, Gurdaspur, parts of Amritsar, Hoshiarpur, Patiala and Mohali districts, while in majority of the area (52.4%), which include most of the central and the south western parts of Punjab, the increase is likely to be between 31 to 40 days (Fig. 2). Similar results were obtained by Van der Waals et al. (2013) in South Africa while using a set of daily weather data simulations for years 1961 to 2050 to calculate past and future trends in pest and disease pressure in potato cropping systems. They observed that the incidence of late blight will increase in winter crops in the Sandveld growing region, because in winter there will be fewer days below the minimum temperature of 10°C.

Global perspective of impact of climate change on late blight severity also corroborates the above findings.

Currently, late blight is not a serious problem in autumn in the state of Punjab, Haryana and parts of Uttar Pradesh, primarily due to sub-optimal temperature regimes during December and January. However, severe outbreaks of late blight have been witnessed during years 1997-98 and 2006-07 with rise in ambient temperature coupled with high RH, when average crop losses in this region exceeded 40% resulting in acute shortage of potatoes in the country (Singh et al., 2013). The results from the present study have revealed that the temperature is likely to increase further by the year 2055 which will bring about 10 to 70 days increase in late blight favourable days. Highest increase is expected in those areas which had least number of late blight favourable days in year 2000. While the area with most late blight favourable days in year 2000 is expected to see a little change in late blight favourable days by year 2055 (Table 1). In general, out of the 14 districts, 7 districts are likely to have about 5 months or more favourable period to late blight. When the average was taken over the
districts, the number of late blight favourable days in year 2000 were 105 during the potato growing season which is likely to increase to 135 days by year 2020 and 148 days by year 2055 (Fig. 3).

In the year 2000, the result showed that despite favourable RH, the congenial temperature threshold levels were not available for a number of days during middle of the season in different districts resulting in late blight free period ranging from 24 days in Patiala to 95 days in Jalandhar districts (Fig. 4). With likely increase in temperature in year 2020, although the late blight appearance is expected to be delayed in all the districts but late blight free days during mid season are also likely to decrease. However, by year 2055 the further rise in temperature is going to eliminate late blight free days in all the districts of Punjab. As a result, blight favourable days during the potato crop growth season in Punjab are likely to increase by 30 days by year 2020 and 43 days by year 2055 over baseline year 2000 (Table 1). In a similar study conducted by Kocmankova et al. (2007) to assess the risk of early outbreaks or increase in the intensity of late blight under climate change in central Europe in year 2050 using DYMEX model, a marked change in the infection pressure and higher number of favourable days for late blight outbreaks were reported under all climate change scenarios, due to increase in temperature. Similar results were indicated in the study of Zalud et al. (2008) where weather driven NegFry model was used to estimate future late blight occurrence under climate change scenarios. Chakraborty et al. (2000) suggested that the most likely impact of climate change will be in the geographical distribution of plant disease. Global perspective of impact of climate change on late blight severity also corroborates the above findings. It was revealed that with rise in global temperature of 2°C, there will be lower risk of late blight in warmer areas (<22°C) and higher risk in cooler areas (>13°C). Earlier onset of warm temperatures could result in an early appearance of late blight disease in temperate regions with the potential for more severe epidemics and increased number of fungicide applications needed for its control (Wallin and Waggoner, 1950).

In western Uttar Pradesh, where temperature is comparatively warmer during the potato crop season as compared to Punjab, the model did not show any break in late blight favourable days during mid season under all the three temperature scenarios (years 2000, 2020 and 2055). With the likely increase of 1.08°C and 2.98°C in years 2020 and 2055 respectively during the potato growth season, the mean number of late blight favourable days decreased by 7 and 27 days in years 2020 and 2055 respectively in western Uttar Pradesh. The reduction in number of late blight favourable days was on two counts; the delay in late blight appearance and reduction in late blight favourable period towards the end of the season. It indicates that the late blight favourable days will shrink from both ends i.e. the start of the crop season as well as end of the season.

In the year 2000, the least number of late blight favourable days (140 to 145) were expected in Agra, parts of Mathura, Mainpuri and Farrukhabad districts which increased in north and north-eastern direction being highest in parts of Saharanpur and Pilibhit districts (166 to 170). Except some parts comprising the districts of Saharanpur, Muzzafarnagar, Baghpat, Meerut and Bijnor where up to 5 days reduction in late blight favourable period is expected, in most parts (about 65% area), the reduction is expected in the range of 6 to 10 days. However, in year 2055, highest decrease (31 to 33 days) is likely to occur in cluster of districts comprising
Fig. 3. Distribution of LB appearance, LB favourable days and delay in LB appearance in western Uttar Pradesh in years 2000, 2020 and 2055.
mainly Badaun, Moradabad, Rampur, Etah, Firozabad, Mainpuri and Farrukhabad. The districts adjoining to this cluster are likely to have 26 to 30 fewer late blight favourable days while Saharanpur, Muzafarnagar and Bijnor districts can witness 15 to 20 days shorter late blight favourable period over baseline year 2000 (Table 2).

**Number of sprays required in seed crop**

Punjab and western Uttar Pradesh are the major quality potato seed production bowls of the country as these areas either remain late blight free for most of the growing season or get less infection due to prevailing climatic conditions. The model has predicted delay in outbreak of late blight in most parts of Punjab due to rise in temperature under both the scenarios. However, with the rise in temperature, especially during the mid season, the late blight favourable period has increased and thus more number of sprays is required to protect the crop under years 2020 and 2055 scenarios. Under the baseline scenario (year 2000), seed crop of potato required 5 to 9 sprays, with lowest number (5 sprays) in the northern parts (Pathankot, Gurdaspur, Amritsar, Hoshiarpur, parts of Kapurthala and Jalandhar), and highest (9 sprays) in most parts of south-eastern Punjab. Overall, a maximum of 6.5 sprays were required to protect potato seed crop in Punjab. In year 2020, two additional sprays may be needed to protect the seed potato crop from late blight in the western parts of Gurdaspur and Amritsar, while in Kapurthala, Ludhiana, Amritsar and Tarn Taran, which are presently major seed potato growing areas, one additional spray may be required. In the eastern parts of Punjab, no change in fungicide sprays is expected, while in Mohali, the requirement of fungicide spray would be reduced by one. However, in year 2055, seed crop in northern parts of Punjab may require up to 3 additional sprays particularly in Gurdaspur, Amritsar, Hoshiarpur, Pathankot, parts of Kapurthala and Jalandhar districts. The number of additional spray required in most part of central Punjab could be 1 to 2 whereas in south-eastern Punjab model has predicted no change in requirement of maximum number of fungicide spray. Overall, 7.3 and 8.0 sprays in years 2020 and 2055 respectively are expected as against of 6.5 in year 2000 (Table 1). Studies carried out in Finland predicted that for each 1°C warming, late blight would occur four to seven days earlier, and the susceptibility period extended by 10 to 20 days (Kaukoranta, 1996).

On the other hand, in western Uttar Pradesh, except for two northern districts namely Saharanpur and Muzaffarnagar which require a maximum of 7 or less sprays, in rest of the area (93% of geographical area) 8 to 9 sprays are required under the baseline scenario year 2000. Model predicted that while in Saharanpur and Muzaffarnagar districts number of sprays would increase by 1 and 2 respectively, it is likely to decrease by one in most parts of southern and south western districts. In rest of the area, representing about 56% of western Uttar Pradesh, no change is likely in number of fungicidal spray in year 2020. Results further indicated that in year 2055, number of fungicide spray will be reduced by up to two in seed crop in most parts of western Uttar Pradesh (80% of the area). Except in a 30-40 Km wide belt along the northern border of western Uttar Pradesh and Muzaffarnagar where requirement of fungicide sprays would increase by 1 to 2 and in Saharanpur district, where 3 to 5 additional sprays would be required for protection of seed crop from late blight, the need of fungicide sprays are projected to decrease in western Uttar Pradesh (Table 2).
The simulation study using JHULSACAST model has revealed that late blight appearance in Punjab in year 2020 is likely to be delayed by 0 to 6 days over the baseline year 2000, due to projected high temperature in year 2020 (1.08°C). A further increase in temperature, in year 2055, would delay late blight appearance in Punjab by 12 to 14 days over year 2000. However, the late blight favourable days during the potato growth season, which ranged from 140 days in southern Punjab to 170 days in northern Punjab. The simulation study using JHULSACAST model has revealed that late blight appearance in Punjab in year 2020 is likely to be delayed by 0 to 6 days over the baseline year 2000, due to projected high temperature in year 2020 (1.08°C). A further increase in temperature, in year 2055, would delay late blight appearance in Punjab by 12 to 14 days over year 2000. However, the late blight favourable days during the potato growth season, which ranged from 140 days in southern Punjab to 170 days in northern Punjab.
Punjab in year 2000, are likely to increase by up to 40 days in year 2020 and 10 to 70 days in year 2055, depending upon the location, due to reduction in late blight free days during mid season in year 2020, which is likely to be eliminated in year 2055. In western Uttar Pradesh, likely increase in temperature by the year 2020 would cause delay in appearance of late blight up to 8 days, which is further projected to be delayed by 15 to 18 days in year 2055. As against Punjab, no blight free days were simulated by the model due to prevailing higher temperature in western Uttar Pradesh, as such in the future climate scenario, a likely decrease of 7 and 27 days in years 2020 and 2055 respectively, in late blight favourable days is expected in western Uttar Pradesh.

CONCLUSIONS

The increase in late blight favourable days in Punjab is expected to increase the average number of sprays required to protect the seed crop from 6.5 sprays in year 2000 to 7.3 and 8.0 sprays in years 2020 and 2055, respectively. On the other hand, due to reduced favourable period for development of late blight, in most of the western Uttar Pradesh (56% of the geographical area) no change in is expected in number of sprays required in year 2020, while in rest of the area the number of sprays would either increase or decrease by one. However, in year 2055, requirement of fungicide sprays is likely to be reduced two in seed crop in most parts of western Uttar Pradesh (80% of the area) compared to baseline scenario.

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MS received: 11 July 2014; Accepted: 19 June 2015