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## Spatial and Temporal Distribution of *Iris yellow spot virus* and Thrips in Colorado Onion Fields

**Howard F. Schwartz**, Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO 80523; **David H. Gent**, USDA-ARS and Department of Botany and Plant Pathology, Oregon State University, Corvallis, CO 97331; **Scott M. Fichtner**, Crop Production Services, Fresno, CA 93711; **Rajiv Khosla**, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523; **Linda A. Mahaffey**, USDA-APHIS, Bakersfield, CA 93308; **Matthew A. Camper** and **Whitney S. Cranshaw**, Department of Bioagricultural Sciences and Pest Management, Colorado State University, Fort Collins, CO 80523

Corresponding author: Howard F. Schwartz. [howard.schwartz@colostate.edu](mailto:howard.schwartz@colostate.edu)

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### Abstract

*Iris yellow spot virus* and its onion thrips vector (*Thrips tabaci*) are yield limiting pests of onion in the western United States. This two-year project investigated the relationship of iris yellow spot to thrips populations, soil properties, and grower management practices in six onion fields during 2005 and 2006 in Colorado. Thrips density (average number of thrips per plant per day) was negatively associated with soil pH ( $r = -0.61$ ). The incidence of iris yellow spot at harvest was positively associated with organic matter, zinc, potassium, percent sodium, percent hydrogen, copper, iron, and soil pH. Thrips-days had a clear non-linear association with disease incidence at harvest. Onion plant population was positively associated with levels of iron, phosphorus, potassium, and zinc; and negatively associated with calcium, salts, percent potassium, and cation exchange capacity (CEC). Marketable (medium or larger sized bulbs) yield was negatively associated with phosphorus and percent potassium, and positively associated with salts, calcium, and CEC. Results from this project could contribute to the development of a risk index to predict potential risk from *Iris yellow spot virus* and its onion thrips vector.

### Introduction

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Onion (*Allium cepa* L.) is an economically important crop in the United States, generating nearly one billion dollars in farm receipts in 2008 (27). United States onion production ranges from 60,000 to 70,000 ha annually, with nearly 80% of production (54,000 ha) in the western region. A significant portion of the United States and world onion seed is also produced in the western United States, primarily in the Pacific Northwest (43). Because of the high value of onion, the crop is intensively managed for weeds, insect pests, and diseases, largely through regular and routine pesticide applications.

Various thrips species (Thysanoptera: Thripidae) cause damage to onion in western United States production regions and are managed primarily with frequent insecticide applications (23,32). In spite of chemically intensive management, thrips continue to cause significant and increasing damage to onion because of widespread insecticide resistance (1,37). Therefore, thrips are a primary constraint to continued productive and sustainable onion production.

In addition to feeding injury caused by thrips, the thrips-transmitted tospovirus *Iris yellow spot virus* (IYSV) has emerged as a devastating pathogen and widespread disease of onion and other *Allium* species in the western United States (15,25), including chive, leek (16, 35), and garlic (2). Management of iris yellow spot (IYS), the disease caused by IYSV, is difficult and, currently, incomplete. Current management strategies include selection of cultivars less susceptible to the disease and/or vector (9), increased plant population (13,14), selection of transplants free of IYSV and thrips (15), elimination of volunteer onions from previous crops and weeds during current cropping (15,34), and separation of onion bulb and seed crops to break the green-bridge reservoirs of the thrips vector and the virus (15). Many growers also have implemented intensive thrips insecticide programs, which may provide some suppression of the disease (36).

The spatial distribution of infected plants varies within and among onion fields depending on cultivar, plant population, and location in the field. Infected plants most often are distributed randomly and secondary spread of IYS within fields appears limited, although the highest IYS incidence was often found on the borders of fields with the lowest incidence near the field centers in Colorado (13). The value of insecticides in disease management is still unresolved. Schwartz et al. (36) found a linear relationship between thrips density in late June and the incidence of IYS in early to mid-August. However, insecticide applications for thrips management often is regarded as ineffective for management of tospovirus diseases since viruliferous thrips originating from outside a field may be more important sources of inoculum compared to secondary spread from in-field thrips dispersal (17).

Cultural practices can substantially influence thrips population dynamics (31,41) and the incidence of tospoviruses (41). Managing nitrogen fertilization has reduced thrips populations on numerous crops (3,24,31), and also may be useful in tospovirus management (41). Nitrogen management may be an important component of thrips and IYS in onion, but studies quantifying this relationship have not been reported. Additionally, straw mulch applied to the center of onion beds in the early to mid-bulb growth stages reduced density of thrips by 33 to 54% (20,36), and overhead irrigation can reduce thrips populations on plants (29).

Since the introduction of IYSV into Colorado, the pathogen has been confirmed from an increasing number of fields and has continued to expand to new areas each year (13). Due to the speed at which the virus has moved within the state, surveys were carried out to study the spatial patterns and spread of this priority disease. Thus far, no known alternate host has been confirmed in Colorado, although several weed species have tested positive by double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) in Colorado (15), Idaho (30), Georgia (28), and Utah (10,11). Additionally, studies have found that the virus may arrive on onion transplants imported into Colorado, primarily from areas where the virus is already known to occur (22,23). The only known vector of IYSV, *Thrips tabaci* Lindeman, is prevalent in Colorado and often has been found on imported onion transplants (23,33,34). A recent study in New York monitored thrips populations and virus incidence in transplanted and direct-seeded fields, and concluded that concentrating the spatial arrangement of crops based on similar harvest dates could reduce spread of IYSV to later-maturing fields (18). Preliminary studies and observations have suggested an association between the incidence of IYS and plant stress (13). The goal of this project was to identify edaphic factors and cultural practices associated with thrips density and the incidence of *Iris yellow spot virus* in Colorado.

### Investigating the Relationship of IYSV to Thrips in Onion Fields

**Field sampling methods.** The spatial and temporal variability of IYS incidence and severity, thrips populations, and yield of onion bulbs were mapped and interpolated as described by Gent et al. (13). Briefly, two representative fields in two onion production regions (Front Range and West Slope) with a history of IYS in Colorado were selected in each of 2005 and 2006.

The perimeter of each field was mapped by walking the border using a differentially-corrected GPS unit and MapInfo Professional Version 6.5 FarmGPS software (MapInfo Corp., Troy, NY). A 0.2-ha virtual grid and georeferenced random sampling points (50 to 60 points per 20- to 30-ha field) were superimposed on each field in FarmGPS software, and each point was marked with a flag. Cultivars were chosen by growers for adaptation to local growing conditions including soil factors, and were not known to vary in their responses to infestation by thrips or infection by IYSV.

Plant population and IYS incidence from a 3-m section of one bed centered on the flag at each sampling point was recorded, along with the number of thrips on 10 randomly selected plants. Onion crops grown from direct-seeded and transplanted production systems varied from 2-row, 75-cm bed to 3- to 4-row, 125- to 150-cm bed, with an 8- to 10-cm spacing between rows on the bed. Plant samples (3 to 10 plants per site per field) were tested by double antibody sandwich enzyme-linked immunosorbant assay (DAS-ELISA, Agdia, Elkhart, IN) to verify IYSV presence and confirm the cause of suspect IYS symptoms. The number of thrips larvae and adults per 5 to 10 plants per site was counted visually and speciated by W. Cranshaw and personnel during three to five stages of plant development each year (36). Two to four weeks preharvest, six 2.5-cm soil cores were collected from a depth of 30 cm from each site and analyzed for pH, texture (39), and concentrations of soluble salts and major nutrients by a commercial laboratory (MDS Harris, Lincoln, NE). As crops with outbreaks of IYS matured, the plants in a 3-m plot at each site were mechanically topped and harvested, sorted according to bulb size (colossal as 10 cm or larger, jumbo as 7.6 to 10 cm, medium as 5.7 to 7.6 cm, and total marketable bulbs as combined medium to colossal) and weighed to estimate total and bulb grade yield components (33).

**Statistical analyses.** The association of edaphic factors to thrips density, IYSV incidence, yield, and onion plant population were quantified by Pearson's correlation coefficient. Analyses were conducted in SAS Version 8.1 (SAS Institute Inc., Cary, NC) using the CORR procedure. Thrips density over all assessment dates noted below in each plot was expressed as cumulative "thrips-days," a standard summary variable similar to area under the disease progress curve (40). Thrips-days (35) were calculated as:

$$\sum_{i=1}^n [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

where  $x_i$  is mean number of thrips at time  $t_i$ . Relative area under the disease progress curve (rAUDPC) was calculated for each plot as:

$$\left\{ \sum_{i=1}^n [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i] \right\} / t_n - t_i$$

where  $x_i$  is IYS incidence at time  $t_i$ . This is simply a time-standardized version of the familiar area under the disease progress curve (21). Maps were produced from data interpolated using the inverse distance weighting technique based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points (19) (Fig. 1 and 2).

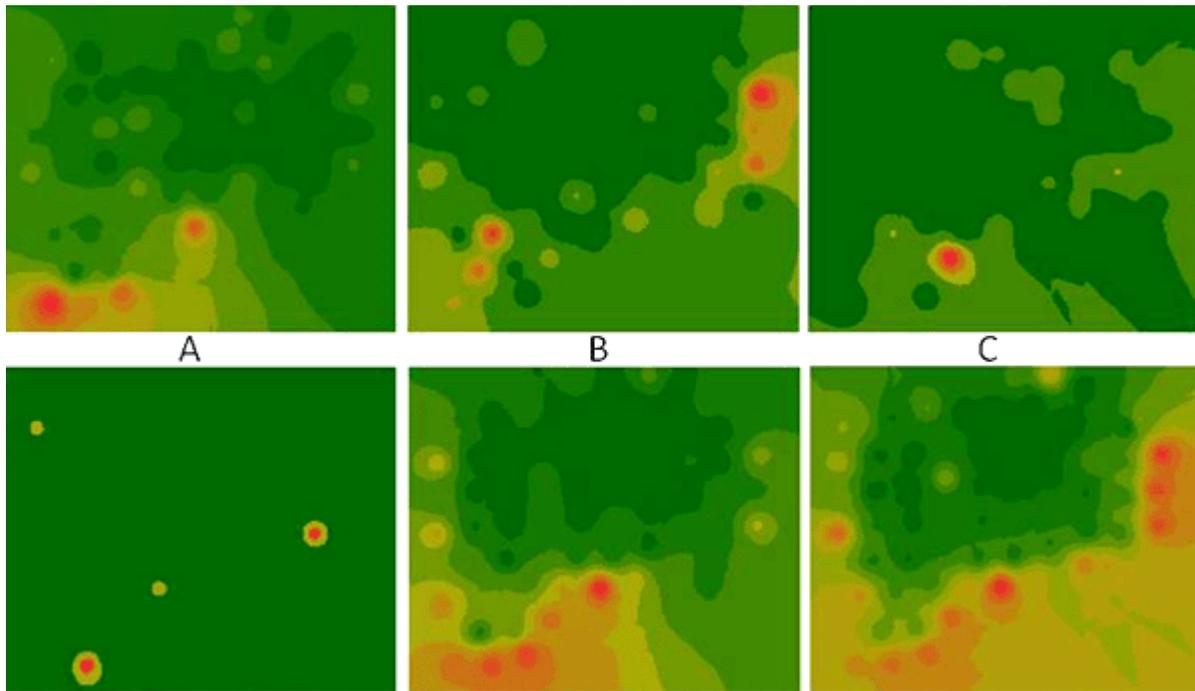


Fig. 1. Spatial distribution of the density of thrips (upper row) and the corresponding incidence of iris yellow spot (IYS) (lower row) on 12 July (A), 8 August (B), and 15 August (C) at the Peckham direct-seeded onion bulb field in 2005 in Colorado. Dark green areas indicate where thrips density or incidence of IYS was 0, while red indicate areas of highest thrips density (57.0/plant) or IYS incidence (97.2%). Maps were produced from data interpolated using the inverse distance weighting technique based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points (19).

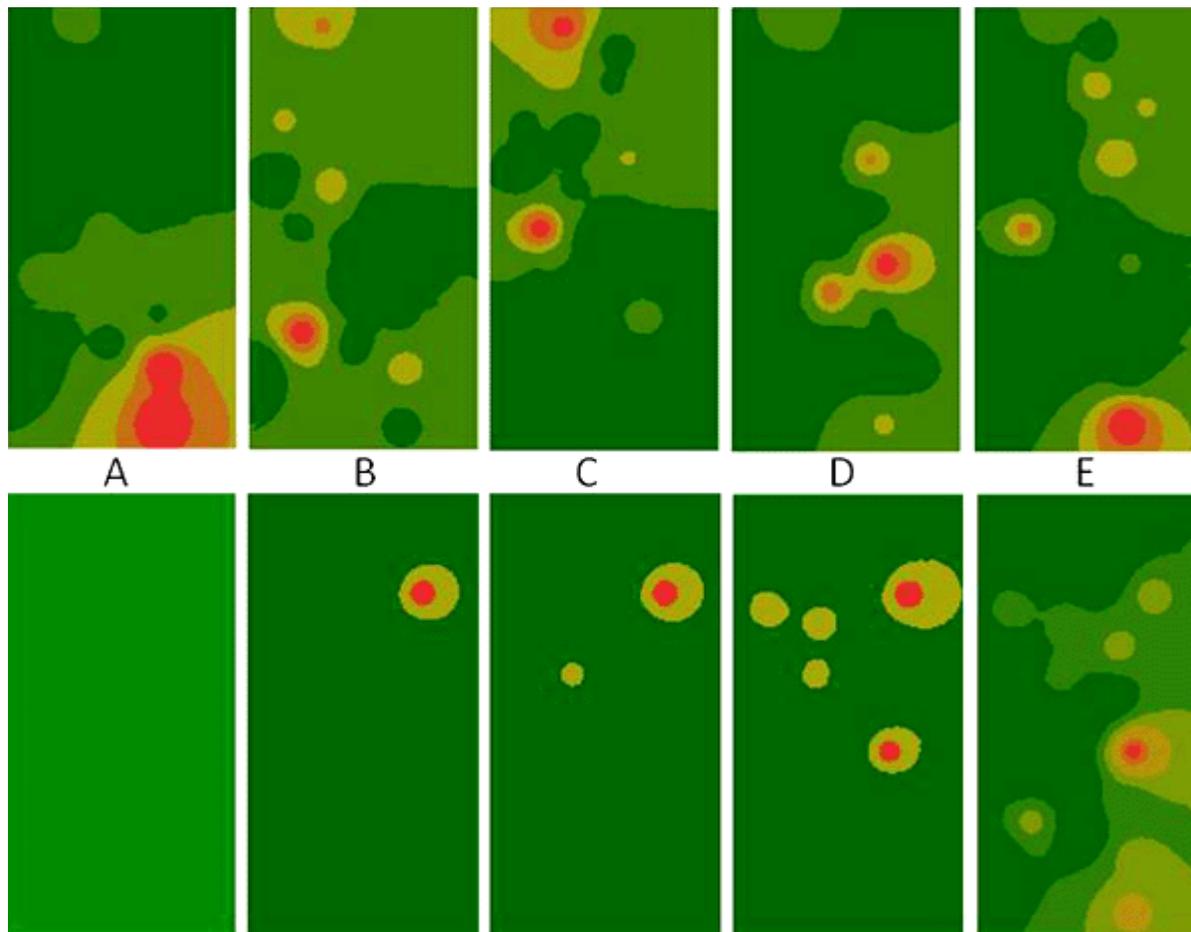


Fig. 2. Spatial distribution of thrips (upper row) and the corresponding incidence of iris yellow spot (IYS) (lower row) on 7 July (A), 25 July (B), 9 August (C), 18 August (D), and 31 August (E) from the Loma-North onion field in 2005 in Colorado. Dark green areas indicate where thrips density or incidence of IYSV was 0, while red indicate areas of highest thrips density (64.4/plant) or IYSV incidence (7.0%). Maps were produced from data interpolated using the inverse distance weighting technique based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points (19).

**2005 season.** Four fields were selected for the survey in 2005. Of these, two fields were on the Western Slope in western Colorado and two were adjacent to the Front Range in eastern Colorado. On the Western Slope, two direct-seeded fields were located near Loma, CO, and identified as Loma-North (4 ha with 21 sampling sites) and Loma-South (4.2 ha with 24 sampling sites). Both fields were furrow-irrigated, with Loma-North planted to the cultivar Vaquero (yellow bulb color, Nunhems USA, Parma, ID), and Loma-South planted to cultivar Talon (yellow bulb color, Bejo Seeds Inc., Oceano, CA).

The two fields located along the Front Range were identified as Peckham-transplant (3.2 ha transplanted crop with 16 sampling sites) and Peckham-seed (13.3 ha direct-seeded crop with 67 sampling sites). Both fields were furrow-irrigated. Peckham-transplant was planted to the cultivar Redwing (red bulb color, Bejo Seeds), and Peckham-seed was planted to the cultivar Tango (red bulb color, Nunhems USA).

IYS incidence assessments were initiated once symptoms were observed on field borders. The ratings were based on incidence of IYS in 3 m of a single row in each flagged plot. Thrips counts were conducted on five individual plants within each plot to determine the density of thrips. The survey at Loma-North began 11 July with additional surveys on 25 July, and 9, 18, and 31 August. Soil samples were collected on 18 August. The Loma-South site was surveyed on 11 and 25 July, 9 and 31 August, and 13 September. Soils were collected on 18 August. Thrips and IYS assessments at the Peckham-transplant site began 24 June with additional ratings on 7 July, 15 July, 23 July, and 8 August. Yield samples were collected from 3 m of the bed at each flagged plot on 15 August. At

the Peckham-seed site the survey included thrips population counts and IYS incidence on 12 July, and 8 and 15 August. Soil samples were collected from plots on 15 August, and a complete soil analysis was conducted on each sample.

**2006 season.** Two direct-seeded fields adjacent to the Front Range were selected and named Fort Collins (13 ha with 67 sampling sites) and Peckham (20 ha with 56 sampling sites). The Fort Collins field was furrow-irrigated and the other site was sprinkler-irrigated. The Fort Collins field was planted to the cultivars Teton and Tioga (yellow bulb color, Monsanto Vegetable Seeds, Oxnard, CA), and Peckham was planted to the cultivar Talon.

Disease and thrips assessments were conducted as described previously. The field survey at the Fort Collins site began 20 June with additional ratings on 28 June, and 5 and 21 July. Disease incidence was low across the field (< 1% incidence), and therefore yield data was not collected at this site. At the Peckham site, thrips counts were taken 12 July and 1 August, and IYS incidence was assessed on 1 and 28 August. Soil samples were collected on 12 August. Yield samples were collected on 31 August.

### Survey Results

Table 1 summarizes the range in values recorded for IYS, thrips, soil and yield variables measured in the six fields during this 2-year period. Thrips populations consisted predominantly of onion thrips (> 75% *T. tabaci* from any site, date or year); with occasional recovery of 10 to 25% *Frankliniella occidentalis*, or < 10% *F. schultzei*). The soil variables were generally within limits recommended for the production of dry bulb onions in the western United States (4,42), with no apparent nutrient deficiencies or toxicities observed on any plants at any site.

**2005 season.** Both the incidence of IYS (97 to 100% incidence in individual plots) and populations of thrips (30 to 100/new crop plant) at the two Peckham fields were large (Table 1). *Iris yellow spot virus* was identified and confirmed from leaves of volunteer onion plants sampled 2 March 2005 in the vicinity of a Peckham field that was surveyed in 2004 and found to be positive for IYSV by DAS-ELISA. The 2005 survey locations outside of the Peckham area had low levels ( $\leq$ 7% incidence) of IYS in any of the survey plots.

Symptoms of IYS were observed on few plants in the Western Slope sites. Thrips populations were low (< 2/plant) for much of the season with counts increasing later in the season to a mean of 15/plant. At the Loma-South direct-seeded site, thrips populations were low (< 10/plant) until late in the season near plant maturity, and incidence of IYS was < 1% on all sampling dates (Table 1).

**2006 season.** Mean incidence of IYS was < 1% at Fort Collins, and only reached 17% on new crop onion plants near maturity at Peckham in 2006. *Iris yellow spot virus* was identified and confirmed from leaves of volunteer onion plants sampled 1 May 2006 in the vicinity of a Peckham field that had been surveyed in 2005 and found to be positive for IYSV.

Table 1. Summary of field, plant, edaphic, thrips and *Iris yellow spot virus* data (low to high) collected from six onions fields in western and northeastern Colorado during 2005 and 2006.

Variable	2005				2006	
	Loma-North	Loma-South	Peckham seed	Peckham transplant	Fort Collins	Peckham
Field size (ha)	4.0	4.2	13.3	3.2	6.1	20.0
No. of sample sites (0.2 ha grid)	21	24	67	16	34	56
Plant stand (plants/3 m bed)	48.2	60.4	--	48.7	55.7	83.7
IYSV incidence - season (%)	0-7.0	0	2.3-97.2	73.5-100.0	0	0-56.6
IYSV-rAUDPC <sup>w</sup>	0-0.0259	0-0.0081	0.0020-0.5120	0.4409-0.8754	0	0-0.2830
No. of thrips-season (total of 1st to last sample/plant)	4.6-64.4	8.2-103.8	30.0-570.0	100.0-374.0	12.8-30.8	1.1-11.4
Thrips-tDays <sup>x</sup>	0.09-1.26	0.13-1.62	0.18-3.35	2.22-6.94	0.41-0.99	0.06-0.57
Total marketable yield (MT/ha) <sup>y</sup>	4.5-54.4	0.7-32.0	0.6-23.5	14.4-52.0	8.3-29.1	0.1-35.5
Soil texture <sup>z</sup>	CL, L, SiL	CL, L, SiL	LS, SL	SL	SL	SL
Soil pH	7.7-8.2	7.7-8.4	6.1-7.4	5.7-7.0	7.7-8.1	7.3-8.1
Organic matter (%)	1.0-1.3	1.1-1.6	0.8-1.4	0.8-1.5	1.1-1.8	0.5-1.9
Soluble salts	0.5-4.8	0.5-3.6	0.3-0.8	0.0-0.6	0.6-3.9	0.2-0.9
Nitrogen (ppm)	20-523	12-124	9-96	13-103	4-139	3-88
Phosphorous (ppm)	11-33	10-39	30-146	32-76	5-39	24-169
Potassium (ppm)	85-136	96-150	102-363	137-359	149-379	136-653
Magnesium (ppm)	218-323	153-334	137-313	160-269	533-1084	95- 383
Calcium (ppm)	3454-4657	3438-8067	802-1762	922-1569	2142-4419	558-1997
Sulfur (ppm)	26-495	25-999	17-80	24-54	240-999	6-67
Zinc (ppm)	1.0-2.5	1.1-2.4	4.2-15.8	4.8-16.3	0.6-1.4	2.0-30.7
Manganese (ppm)	1.3-3.2	0.9-3.4	0.8-46.4	1.4-46.4	4.1-11.5	4.6-19.8
Copper (ppm)	1.4-3.0	1.5-2.5	2.6-11.5	3.6-11.5	0.9-1.8	1.5-13.8
Iron (ppm)	6.8-12.9	8.8-24.4	16.4-52.7	19.7-46.3	5.4-12.8	17.6-53.6
Boron (ppm)	0.8-1.1	0.8-1.0	0.7-1.1	0.7-1.0	1.8-3.4	0.7-2.1
Sodium (ppm)	112-1189	98-218	75-208	111-162	108-475	71-230
% potassium (base saturation)	1.1-1.5	0.7-1.8	3.4-11.1	4.1-8.2	2.5-3.8	5.5-11.2
% magnesium (base saturation)	9.1-10.3	3.0-12.6	15.9-23.0	14.9-19.9	19.3-32.5	17.8-21.4
% calcium (base saturation)	73.9-87.2	83.2-95.2	55.0-73.6	59.6-71.9	57.5-74.6	63.1-70.0
% sodium (base saturation)	2.4-16.4	1.0-3.9	4.0-9.8	4.0-7.5	1.9-7.3	2.8-7.3
% hydrogen (base saturation)	0	0	0-13.4	0-13.4	0	0
CEC	20.0-31.5	11.5-42.3	5.8-13.0	7.6-12.0	18.0-32.8	5.2-14.9

(continued)

Table 1 (footnotes).

<sup>w</sup> Relative area under the disease progress curve (rAUDPC) = AUDPC values divided by the total area of the graph (21).  $AUDPC = \sum [(x_{i+n} + x_i)/2] [t_{i+1} - t_i]$  where  $x_i$  is incidence of IYS at the  $i$ th observation,  $t_i$  = time in days at the  $i$ th observation, and  $n$  = total number of observations. IYS incidence measured as number of symptomatic/total plants in a 3-m section at each sampling point.

<sup>x</sup> t-days = Thrips-days calculated by dividing the average number of thrips/plant by the number of days between the first and last sample for each experiment (38).

<sup>y</sup> Total marketable yield = combined weight of medium, jumbo, and colossal bulbs (32).

<sup>z</sup> CL = clay loam, L = loam, LS = loamy sand, SL = sandy loam, SiL = silt loam. Soil texture for 2006 was obtained from Soil Survey Staff (39).

**Pearson's correlations.** Table 2 presents correlation analyses of variables measured including IYS incidence, thrips density, plant density, yield and various soil nutrient and texture measures combined across the six fields monitored during 2005 and 2006. Thrips density, expressed as thrips-days, was negatively associated with pH ( $P < 0.01$ ). The incidence of IYS at harvest was positively associated at  $P < 0.05$  with organic matter, zinc, potassium, % sodium, and % hydrogen; and at  $P < 0.01$  with copper, iron, and soil pH. The incidence of IYS was most strongly positively associated with sodium content ( $r = 0.40$ ,  $P = 0.011$ ; Fig. 3A) and negatively associated with pH ( $r = -0.61$ ,  $P < 0.0001$ ; Fig. 3B). The correlation of plant population to incidence of IYS varied among sites ( $r = 0.14$ ,  $P = 0.082$ ), with a significant association between the two variables at three of the four sites where the two variables were  $> 0$  (Fig. 3C).

Table 2. Pearson's correlation coefficients for plant population, yield, thrips density, Iris yellow spot disease incidence, and edaphic characteristics for six commercial onion fields in western and northeastern Colorado during 2005 and 2006.

Edaphic factor	Plant population <sup>v</sup>	Yield <sup>w</sup>	Thrips-days <sup>x</sup>	IYS incidence <sup>y</sup>	rAUDPC <sup>z</sup>
% organic matter	-0.08	0.21	-0.07	-0.37*	-0.27
Nitrogen	-0.32	0.10	0.20	-0.06	-0.03
Bray 1 P	0.57**	-0.37*	0.01	0.24	0.19
Potassium	0.41**	-0.19	-0.15	-0.02	0.01
Magnesium	-0.21	0.32	-0.03	-0.38*	-0.31
Calcium	-0.45**	0.41**	-0.15	-0.54**	-0.44**
Sulfur	-0.32	0.34	0.06	-0.29	-0.23
Zinc	0.47**	-0.34	-0.01	0.36*	0.32
Manganese	0.16	-0.21	-0.02	0.28	0.29
Copper	0.32	-0.23	0.01	0.44**	0.43**
Iron	0.38*	-0.37	0.18	0.53**	0.48**
Boron	0.08	0.14	-0.16	-0.35	-0.30
Soil pH	0.20	0.11	-0.44**	-0.61**	-0.56**
Salts	-0.42**	0.35*	0.11	-0.32	-0.27
Sodium	-0.28	0.19	0.04	-0.22	-0.17
% potassium	0.54**	-0.44**	-0.01	0.36*	0.31
% magnesium	0.16	-0.06	0.11	0.09	0.06
% calcium	-0.27	0.25	-0.20	-0.40**	-0.37*
% sodium	0.07	-0.19	0.25	0.40*	0.33
% hydrogen	-0.17	-0.03	0.23	0.40*	0.47**
CEC	-0.44**	0.42**	-0.13	-0.53**	-0.43**

<sup>x</sup> Number of onion plants/3 m of one row/sample site/field.

<sup>w</sup> Yield of colossal and jumbo grade bulbs estimated from 3 m of one row/sample site/field.

<sup>x</sup> Thrips-days were calculated as:

$$\sum_{i=1}^n [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i]$$

where  $x_i$  is the mean number of thrips/plant at time  $t_i$ .

<sup>y</sup> Incidence (%) of plants with iris yellow spot (IYS) symptoms on the final disease assessment near crop maturity.

<sup>z</sup> rAUDPC is relative area under the disease progress curve (21). rAUDPC was calculated as:

$$\left\{ \sum_{i=1}^n [(x_{i+1} + x_i) / 2] [t_{i+1} - t_i] \right\} / t_n - t_i$$

where  $x_i$  is IYS incidence at time  $t_i$ .

\* = significant at  $P < 0.05$ .

\*\* = significant at  $P < 0.01$ .

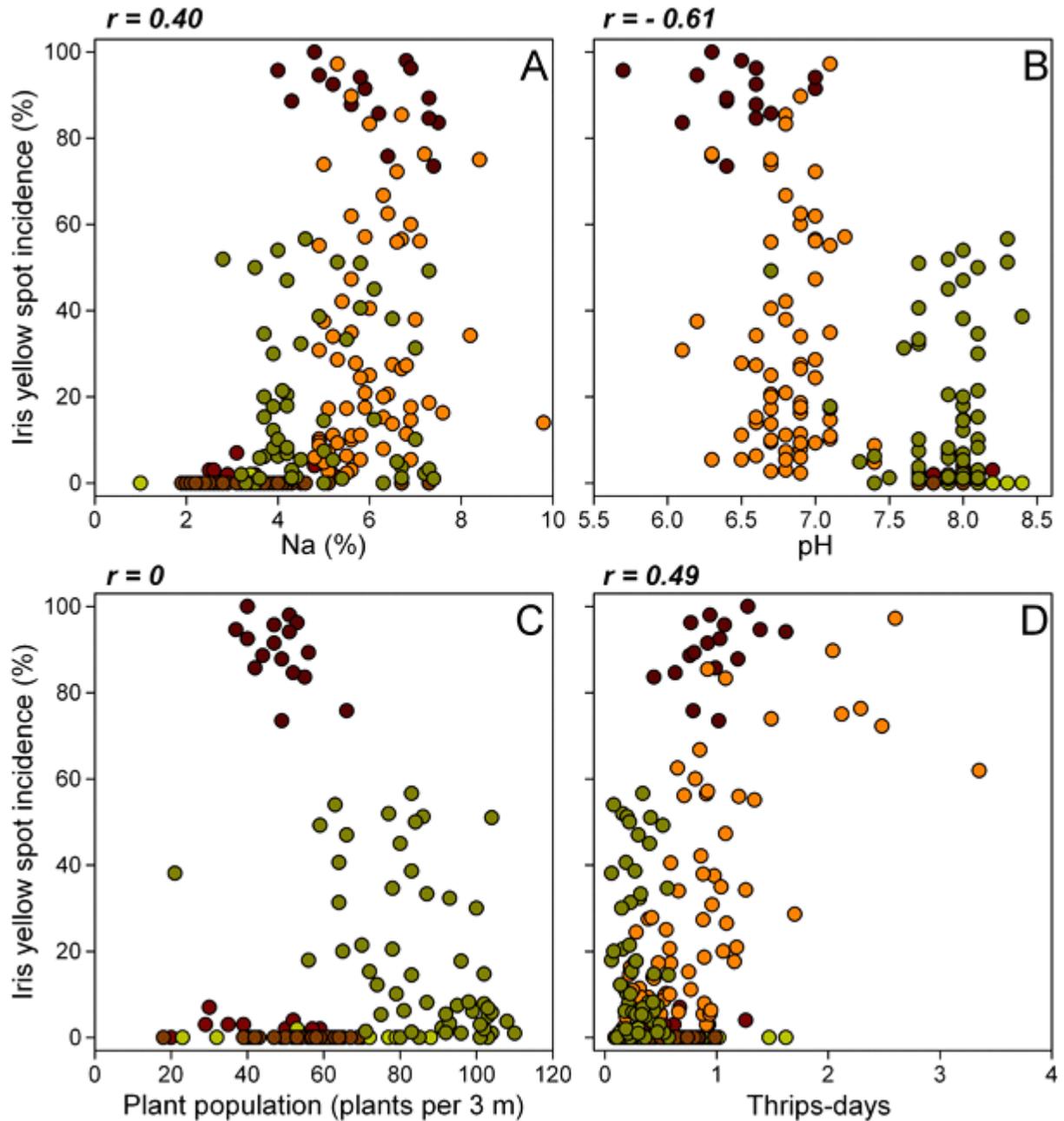


Fig. 3. Scatterplots illustrating the association of the incidence of onion plants with iris yellow spot (IYS) at harvest to percent soil sodium ( $r = 0.40$ ,  $P = 0.011$ ): (A) pH ( $r = -0.61$ ,  $P < 0.0001$ ); (B) plant population ( $r = -0.14$ ,  $P = 0.082$ ); (C), and thrips-days ( $r = 0.49$ ,  $P < 0.0001$ ); (D) in six commercial onion fields in western and northeastern Colorado during 2005 and 2006. A total of 218 plots was assessed among the six fields; data points from a given field are colored similarly.

Thrips-days had a non-linear association with the incidence of IYS at harvest ( $r = 0.49$ ,  $P < 0.0001$ ; Fig. 3D). Maps of thrips density and IYS incidence illustrated general association between greater thrips density and IYS levels (examples shown in Fig. 1 and 2).

Onion plant population was positively associated at  $P < 0.05$  with iron and at  $P < 0.01$  with phosphorus, potassium, and zinc; and negatively associated at  $P < 0.01$  with calcium, salts, % potassium, and CEC. Marketable (medium or larger sized bulbs) yield was negatively associated at  $P < 0.05$  with phosphorus and at  $P < 0.01$  with % potassium; and positively associated at  $P < 0.05$  with salts and at  $P < 0.01$  with calcium and CEC.

## Conclusions

This study identified soil factors that may be significantly associated (positively or negatively) with levels of thrips and IYS under commercial onion production conditions in Colorado. Clearly, many of the variables measured are correlated and the current study was a preliminary attempt to identify edaphic and production factors ( $P < 0.05$ ) that could be potential indicators of IYS risk. No attempts were made to disentangle the complex interrelationships among the variables to determine causal relationships. The scale of the sampling units (individual plots in six commercial onion fields) was too coarse and confounded by natural variability among fields to identify most of the important risk factors. However, several risk factors for thrips (e.g., negative association with soil pH) and IYS (e.g., positive associations with organic matter, zinc, iron, salts, and soil pH) were identified that provide data and direction for future investigations.

Previous reports have suggested that the incidence of IYS may be positively associated with plant stress, primarily soil moisture stress (15). In this study, soil levels of available sodium and hydrogen were positively associated with the incidence of IYS but not thrips density, and soil pH had a negative relationship with both disease incidence and thrips density. This suggests that soil sodicity, a potential indicator of water stress, may affect thrips density and/or IYS. Yield losses in onion caused by thrips feeding injury are known to be exacerbated by moisture stress (12,29). In the current study, soil sodicity may be a surrogate for plant moisture stress due to high salt content of the soil which hampers the ability of plants to take up water from the soil (44).

The effect of plant population on IYS appears to be field specific depending on disease incidence in this study, but consistent with previous studies on onion (13,14) and *Tomato spotted wilt virus* (TSWV) on peanut (5) in that higher planting densities were significantly associated with a lower incidence of disease. The relationship between plant population and incidence of IYS may need more study though, as plant population also was negatively and significantly correlated with soil calcium levels in this study.

Among the variables examined, thrips density had a clear association with incidence of IYS. Schwartz et al. (36) reported a linear relationship between the mean number of thrips on onion plants treated with insecticides and the incidence of IYSV at harvest four to six weeks later. In that study, thrips density explained 59 to 61% of the variability in disease incidence. Insecticide applications generally are regarded as ineffective for managing tospovirus diseases (7,8), a phenomenon often attributed to limited secondary spread of the thrips and consequently the virus within fields. However, in field-grown tomatoes, insecticides have provided some suppression of TSWV (26). Mapping of thrips and IYS incidence during outbreaks (Fig. 1 and 2) in this study suggests that some degree of secondary spread of both can occur. This information, as well as research by others (36), suggests that timely insecticidal control of thrips might be an important disease management strategy for IYS.

Knowledge gained in this study could be used, in part, to create an IYS risk index for onion, similar to the *Tomato spotted wilt virus* risk index for peanut (5,6). This index could be valuable for future testing and validation by researchers and use by growers and crop consultants to integrate historical and current information on crop, pest, disease and weather records and forecasts to determine the relative risk of an IYS epidemic in a given field or production region. An IYS risk index could help identify high risk situations and direct growers to avoid cultural practices that may exacerbate losses to thrips and IYS. Based on this and previous studies (9,13,15,36), we propose that an IYSV risk index should include measurements of thrips density, crop history (e.g., *Allium* spp.), weed composition and density, production stresses (e.g., levels of soil sodium or other salts), plant population, use of straw mulch or non-host cover crops, and cultivar susceptibility to thrips and IYSV. Development of such a risk index could provide a mechanism to disseminate information related to IPM strategies that could be employed to address thrips and IYS outbreaks in Colorado and elsewhere.

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## Literature Cited

1. Al-dosari, S. A. 1995. Development of an IPM system for onion thrips (*Thrips tabaci* Lindemann) as a pest of bulb onions. Ph.D. diss. Colorado State Univ., Fort Collins, CO.
2. Bag, S., Rogers, P., Watson, R., and Pappu, H. R. 2009. First report of natural infection of garlic with Iris yellow spot virus in the United States. *Plant Dis.* 93:839.
3. Brodbeck, B., Stavisky, J., Funderburk, J. E., Andersen, P. C., and Olson, S. M. 2001. Flower nitrogen status and populations of *Frankliniella occidentalis* feeding on *Lycopersicon esculentum*. *Entomol. Exp. Appl.* 99:165-172.
4. Brown, B. 2000. Southern Idaho fertilizer guide – onions. CIS Bull. 1081, Univ. of Idaho, Moscow, ID.
5. Brown, S., Todd, J., Culbreath, A., Baldwin, J., Beasley, J., Kemerait, B., and Pappu, H. 2002. Tomato spotted wilt of peanut: Identifying and avoiding high-risk situations. Bull. 1165, Univ. of Georgia, Athens, GA.
6. Brown, S., Culbreath, A., Todd, J. W., Gorbet, D. W., Baldwin, J., and Beasley, J. 2005. Development of a method of risk assessment to facilitate integrated management of spotted wilt of peanut. *Plant Dis.* 89:348-356.
7. Coutts, B. A., Thomas-Carroll, M. L., and Jones, R. A. C. 2004. Patterns of spread of *Tomato spotted wilt virus* in field crops of lettuce and pepper: Spatial dynamics and validation of control measures. *Ann. Appl. Biol.* 145:231-245.
8. Culbreath, A. K., Todd, J. W., and Brown, S. L. 2003. Epidemiology and management of tomato spotted wilt in peanut. *Annu. Rev. Phytopathol.* 41:53-75.
9. du Toit, L. J., and Pelter, G. Q. 2005. Susceptibility of storage onion cultivars to iris yellow spot in the Columbia Basin of Washington, 2004. *Biol. Cultural Tests* 20:V006.
10. Evans, C. K., Bag, S., Frank, E., Reeve, J. R., Ransom, C., Drost, D., and Pappu, H. R. 2009. Natural infection of *Iris yellow spot virus* in twoscale saltbush (*Atriplex micrantha*) growing in Utah. *Plant Dis.* 93:430.
11. Evans, C. K., Bag, S., Frank, E., Reeve, J. R., Ransom, C., Drost, D., and Pappu, H. R. 2009. Green foxtail (*Setaria viridis*), a naturally infected grass host of *Iris yellow spot virus* in Utah. *Plant Dis.* 93:670.
12. Fournier, F., Boivin, G., and Stewart, R. K. 1995. Effect of *Thrips tabaci* (Thysanoptera:Thripidae) on yellow onion yields and economic thresholds for its management. *J. Econ. Entomol.* 88:1401-1407.
13. Gent, D. H., Schwartz, H. F., and Khosla, R. 2004. Distribution and incidence of *Iris yellow spot virus* in Colorado and its relation to onion plant population and yield. *Plant Dis.* 88:446-452.
14. Gent, D. H., Schwartz, H. F., and Khosla, R. 2004. Managing *Iris yellow spot virus* of onion with cultural practices, host genotype, and novel chemical treatments. *Phytopathology* 94:S34.
15. Gent, D. H., du Toit, L. J., Fichtner, S. M., Mohan, S. K., Pappu, H. R., and Schwartz, H. F. 2006. *Iris yellow spot virus*: An emerging threat to onion bulb and seed production. *Plant Dis.* 90:1468-1480.
16. Gent, D. H., Martin, R. R., and Ocamb, C. M. 2007. First report of *Iris yellow spot virus* on onion and leek in Western Oregon. *Plant Dis.* 91:468.
17. Gitaitis, R. D., Dowler, C. C., and Chalfant, R. B. 1998. Epidemiology of tomato spotted wilt in pepper and tomato in southern Georgia. *Plant Dis.* 82:752-756.
18. Hsu, C. L., Hopeting, C. A., Fuchs, M., Shelton, A. M., and Nault, B. A. 2010. Temporal dynamics of *Iris yellow spot virus* and its vector, *Thrips tabaci* (Thysanoptera: Thripidae), in seeded and transplanted onion fields. *Environ. Entomol.* 39:226-277.

19. Isaaks, E. H., and Srivastava, R. H. 1989. An Introduction to Applied Geostatistics. Oxford Univ. Press, New York, NY.
20. Larentzaki, E., Plate, J., Nault, B. A., and Shelton, A. M. 2008. Impact of straw mulch on populations of onion thrips (Thysanoptera: Thripidae) in onion. Hort. Entomol. 101:1317-1324.
21. Madden, L. V., Hughes, G., and van den Bosch, F. 2007. The Study of Plant Disease Epidemics. American Phytopathological Society, St. Paul, MN.
22. Mahaffey, L. A. 2006. Diversity, seasonal biology, and IPM of onion-infesting thrips in Colorado. M.S. Thesis, Colorado State Univ., Fort Collins, CO.
23. Mahaffey, L. A., and Cranshaw, W. S. 2010. Thrips species associated with onion in Colorado. Southwest. Entomol. 35:45-50.
24. Malik, M. F., Nawaz, M., Ellington, J., Sanderson, R., and El-Heneidy, A. H. 2009. Effect of different nitrogen regimes on onion thrips, *Thrips tabaci* Lindemann, on onions, *Allium cepa* L. Southwest. Entomol. 34:219-225.
25. Mohan, S. K. 2004. IYSV symptoms and etiology: Observations since 1989. Page 105 in: Proc. 2004 National Allium Res. Conf., Dec. 8-10, Grand Junction, CO.
26. Momol, M. T., Olson, S. M., Funderburk, J. E., Stavisky, J., and Marois, J. J. 2004. Integrated management of tomato spotted wilt on field-grown tomatoes. Plant Dis. 88:882-890.
27. National Agricultural Statistics Service. 2009. Ag Update. USDA/NASS, Lakewood, CO.
28. Nischwitz, C., Gitaitis, R. D., Mullis, S. W., Scinos, A. S., Langston, D. B., and Sparks, A. N. 2007. First report of *Iris yellow spot virus* in spiny sowthistle (*Sonchus asper*) in the United States. Plant Dis. 91:1518.
29. Parrella, M. P., and Lewis, T. 1997. Integrated pest management in field crops. Pages 595-614 in: Thrips as Crop Pests. T. Lewis, ed. CAB Wallingford, Oxon, UK.
30. Sampangi, R. K., Mohan, S. K., and Pappu, H. R. 2007. Identification of new alternative weed hosts for *Iris yellow spot virus* in the Pacific Northwest. Plant Dis. 91:1683.
31. Schuch, U. K., Redak, R. A., and Bethke, J. A. 1998. Cultivar, fertilization and irrigation affect vegetative growth and susceptibility of chrysanthemum to western flower thrips. J. Amer. Soc. Hort. Sci. 123:727-733.
32. Schwartz, H. F., and Bartolo, M. E., eds. 1995. Colorado Onion Production and Integrated Pest Management. Bull. 547A. Colorado State Univ., Ft. Collins, CO.
33. Schwartz, H. F., Epsky, N. D., and Capinera, J. L. 1988. Onion transplant pink root and thrips contamination, and their control in Colorado. Appl. Agr. Res. 3:71-74.
34. Schwartz, H. F., Gent, D. H., Fichtner, S., Hammon, R. W., and Khosla, R. 2004. Integrated management of *Iris yellow spot virus* in onion. Pages 207-212 in: Proc. 2004 National Allium Res. Conf., Dec. 8-10, Grand Junction, CO.
35. Schwartz, H. F., Otto, K., and Pappu, H. R. 2007. First report of *Iris yellow spot virus* in commercial leek (*Allium porrum*) in the United States. Plant Dis. 91:113.
36. Schwartz, H. F., Gent, D. H., Fichtner, S. M., Hammon, R., Cranshaw, R. S., Mahaffey, L., Camper, M., Otto, K., and McMillan, M. 2009. Straw mulch and reduced-risk pesticide impacts on thrips and *Iris yellow spot virus* on western-grown onions. Southwest. Entomol. 34:13-29.
37. Shelton, A. M., Nault, B. A., Plate, J., and Zhao, J. Z. 2003. Regional and temporal variation in susceptibility to lambda-cyhalothrin in onion thrips, *Thrips tabaci* (Thysanoptera: Thripidae), in onion fields in New York. J. Econ. Entomol. 96:1843-1848.
38. Shipp, J. L., Binns, M. R., Hao, X., and Wang, K. 1998. Economic injury levels for western flower thrips (Thysanoptera: Thripidae) on greenhouse sweet pepper. J. Econ. Entomol. 91:671-677.
39. Soil Survey Staff. 2007. Web Soil Survey. Online. USDA-NRCS, Washington, DC.
40. Sparks, A. H., Esker, P. D., Bates, M., Dall Acqua, W., Guo, Z., Segovia, V., Silwal, S. D., Tolos, S., and Garrett, K. A. 2008. Ecology and Epidemiology in R: Disease Progress over Time. The Plant Health Instructor. DOI:10.1094/PHI-A-2008-0129-02.
41. Stavisky, J., Funderburk, J., Brodbeck, B. V., Olson, S. M., and Andersen, P. C. 2002. Population dynamics of *Frankliniella* spp. and tomato spotted wilt incidence as influenced by cultural management tactics in tomato. J. Econ. Entomol. 95:1216-1221.

42. Sullivan, D. M., Brown, B. D., Shock, C. C., Horneck, D. A., Stevens, R. G., Pelter, G. Q., and Feibert, E. B. G. 2001. Nutrient management for onions in the Pacific Northwest. PNW Bull. 546, Oregon State Univ., Corvallis, OR.
43. Thomas, J., Schreiber, A., Pelter, G. Q., and Havens, D. 1997. Washington's small-seeded vegetable industry. Ext. Bull. No. 1829, Washington State Univ., Pullman, WA.
44. Waskom, R. M., Bauder, T. A., Davis, J. G., and Cardon, G. E. 2007. Diagnosing saline and sodic soil problems. Ext. Bull. No. 0.521, Colorado State Univ., Fort Collins, CO.