# Identifying agricultural flood damage using Landsat imagery

**E. Pantaleoni · B. A. Engel · C. J. Johannsen**

**Abstract** During the first two weeks of July 2003, heavy precipitation occurred across the northern and central portions of Indiana, resulting in flooding and ponded water that damaged crops. Landsat 5 Thematic Mapper images were used to identify the level of damage in fields. A supervised classification and temporal change detection were performed with the help of ERDAS Imagine. To examine the recovery rate of crops over time, two methods were used: a change detection matrix and Delta Normalized Difference Vegetation Index. Both methods indicated an improvement in the conditions of the crops two weeks after the end of the heavy precipitation. Correlations between precipitation, crop damage, yield and unharvested area were weak. At the end of the season, the damage caused by flooding and excess precipitation did not greatly affect the yield of crops, especially corn. Soybeans suffered slightly from these rainfall events, and their yield was smaller than in previous years.

**Keywords** Landsat 5 TM · Corn · Soybeans · Damage · Yield · Indiana

## Introduction

The loss of property and agricultural production from severe thunderstorms and flooding is about $3 billion annually in the USA (Myers 1997). From an agricultural point of view, the area affected the most by these types of hazards is the Corn Belt

E. Pantaleoni
Department of Crop and Soil Environmental Science, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

B. A. Engel (✉)
Department of Agricultural & Biological Engineering, Purdue University,
225 S. University Street, West Lafayette, IN 47907-2093, USA
e-mail: peerb@purdue.edu

C. J. Johannsen
Department of Agronomy, Purdue University, West Lafayette, IN, USA

region (Central USA). During the first two weeks of July 2003, heavy showers and thunderstorms occurred in Indiana, which covers part of the Corn Belt. The severe flooding near rivers and ponding (defined as standing water due to heavy precipitation and drainage properties of the soil) caused serious damage to crops, especially in the northwestern and central part of Indiana (Indiana Crop and Weather Report July 2003). The damage included partial or complete loss of plants, increased plant disease, increased insect infestation, and delays in harvesting. According to the Federal Emergency Management Agency (FEMA 2003), about $30 million in grants and low-interest disaster loans were approved to assist in the recovery during the month following the flood.

The U.S. Department of Agriculture (USDA) provides assistance for agricultural losses when a natural disaster has either reduced the expected unit production (i.e. the amount of crop produced in the absence of a disaster) of the crop by more than 50% or has prevented the producer from planting more than 35% of the intended crop extent. This program covers uninsured farmers. Insured farmers are reimbursed based on their insurance policy. It is important for farmers, and the USDA and private insurance companies to assess the severity of the economic loss as quickly and efficiently as possible so that they can obtain or provide, respectively, adequate assistance.

Although ground-based assessment of the damage is appropriate for urban and industrial areas because of the high level of detail generally required by FEMA, a remotely sensed approach might be more useful for establishing the severity and spatial extent of agricultural damage over large and temporarily inaccessible areas (Lillesand et al. 2004). Data acquired by satellite sensors for a quantitative and qualitative assessment of within and between field variability of agricultural crops is becoming an increasingly important source of information for precision farming. Hyperspatial sensors such as IKONOS, and hyperspectral sensors such as Hyperion (Thenkabail 2003) have dramatically increased spatial, spectral, radiometric, and temporal frequencies that make them appealing to applications in precision agriculture. However, Landsat type sensor satellites are of equal importance in precision farming due to the large synoptic view provided, substantial historical archives, reasonable spatial resolution ($30 \times 30$ m$^2$), and well understood spectro-biophysical relationships (Thenkabail and Nolte 1996).

Satellite images obtained in different seasons of the same year enhance the ability to discriminate between vegetation types (Mackey 1990). Multi-temporal data can also help to evaluate hydrological, phonological and compositional changes across seasons and between years. To improve the suitability of multispectral imagery, several indices have been developed. The Normalized Difference Vegetation Index (NDVI) has been used successfully in vegetation monitoring, crop yield assessment and forecasting (Uchida 2001; Prasad et al. 2005; Hayes et al. 1982; Benedetti and Rossinni 1993; Quarmby et al. 1993).

The goals of this work were to: (1) explore whether data from the Landsat Thematic Map (TM) imagery could be used to identify and detect damage to agricultural fields following excessive precipitation at the beginning of July 2003 (mentioned above); (2) determine whether an improvement or deterioration in the physical conditions of the crops after the flood and precipitation could be detected using a post-classification approach and Delta Normalized Difference Vegetation Index (DNDVI) in an area where two Landsat scenes overlapped; and (3) establish

the correlation between crop damage, precipitation, final crop yield and unharvested crop area.

## Materials and methods

### Study area

Indiana is primarily a manufacturing state, but about 75% of the land is used for agriculture. With a growing season of about 170 days and an average rainfall of 102 cm per year, farms have large yields. Grain crops, mainly corn (*Zea mais*) and wheat (*Triticum aestivum*), are important as they support the livestock and dairying industries. Although the urban population exceeds the rural one, many towns are primarily service centers for agricultural communities.

The total study area of 4,267,042 ha comprises 49 counties and encompasses a large part of north and central Indiana. The area of overlap between the two images examined is 881,164 ha (Fig. 1).

### The flood event

During July 2003 Indiana experienced heavy rainfall that caused flooding in northern and central parts. The rain lasted for almost two weeks, but peaks of precipitation and floods occurred mainly between July 5th and 12th. Precipitation totals exceeded 254–308 mm; the entire state averaged about 200% of its normal precipitation for the month (Midwest Regional Climate Center 2003). Figure 2 shows the mean



**Fig. 1** Map of counties of Indiana. The gray color identifies the study area and the checkered pattern identifies the area of overlap of the two Landsat scenes

Legend
Counties
Study area
Area of overlap

Kilometers
0    45    90              180
1: 2,000,000
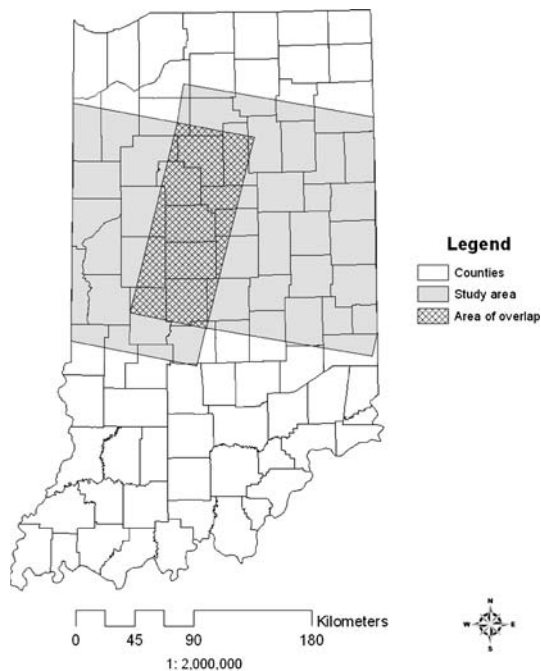
**Fig. 2** Mean July precipitation for six Indiana districts from 1994 to 2003
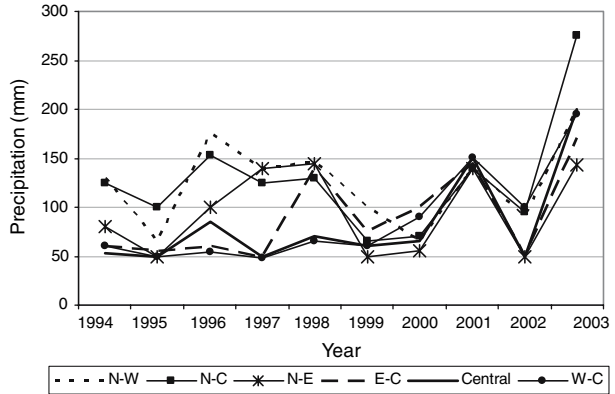


precipitation values for July from 1994 to 2003 in the six districts covering the study area: North-Western (N-W), North-Central (N-C), North-Eastern (N-E), West-Central (W-C), Central and East-Central (E-C).

Landsat imagery and ground reference data

Two Landsat TM images for northern and north central Indiana were available for July 16th and 25th 2003. These images were taken after the main flood event; 4 and 13 days after the end of notable precipitation events, respectively (Fig. 3). Clouds affecting the north-central part of the July 25th scene were masked out, and both images were radiometrically, atmospherically, and geometrically corrected.

We used the National Agricultural Statistics Service (NASS) land use classification from 2003 as ground reference data. It identifies individual fields of corn, soybeans (*Glycine max*) and small grains, in addition to urban and forested areas, pasture land and bodies of water. We also used aerial photographs taken for USDA between July 12th and 20th 2003. Each individual image tile within the mosaic covered a 3.75 × 3.75 min quarter quadrangle plus a 360 m buffer on all four sides. Each aerial photograph covered the extent of a county.

Image classification

The image data were analyzed using a maximum likelihood supervised classification. Pixels that represent recognizable patterns either directly from the scene or with the
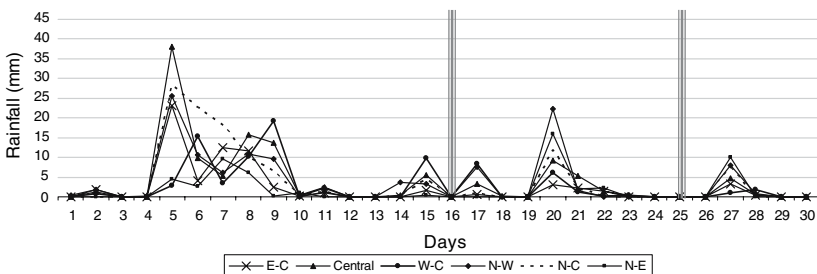


**Fig. 3** July 2003 precipitation for six Indiana districts. The vertical bars correspond to the dates of the Landsat scenes, July 16th and July 25th, respectively

help of other sources are selected. By identifying patterns in the imagery, the computer system can be trained to identify pixels with similar characteristics. If the classification is accurate, each resulting class corresponds to a pattern originally identified (Lillesand et al. 2004).

To select the combination of bands more accurately that separate damaged from healthy crops (the latter are crops that had not been affected either by flooding or ponding), 10 pixels were selected at random within 10 fields selected at random that were affected by the flood. The mean reflectance of the pixels in damaged crops was compared with that for pixels from healthy crops. We repeated the process for both Landsat scenes (Fig. 4). The wavebands that discriminated between the affected and healthy crops the best were 4 (0.76–0.90 μm), 5 (1.55–1.75 μm), and 7 (2.08–2.35 μm). This result agrees with those of Lillesand et al. (2004) and Jensen (2000); the Near Infrared wavelength (Band 4) is useful for determining vegetation vigor and types, and the Mid Infrared wavelengths (Bands 5 and 7) indicate vegetation and soil moisture content. These three bands were used to classify the Landsat images.

Table 1 shows the threshold values used to discriminate between healthy and damaged crops. When the value of the pixels was greater than the threshold, we defined the crop as healthy, and when the value was less than the threshold it was defined as damaged. To ensure an accurate interpretation of the images and the selection of appropriate training samples, we also used aerial photographs and the NASS land use classification from 2003.



**Fig. 4** (**a**) Spectral reflectance of damaged crops and healthy crops on July 16th 2003; (**b**) Spectral reflectance of damaged crops and healthy crops on July 25th 2003. Water and bare soil spectral reflectance are also provided
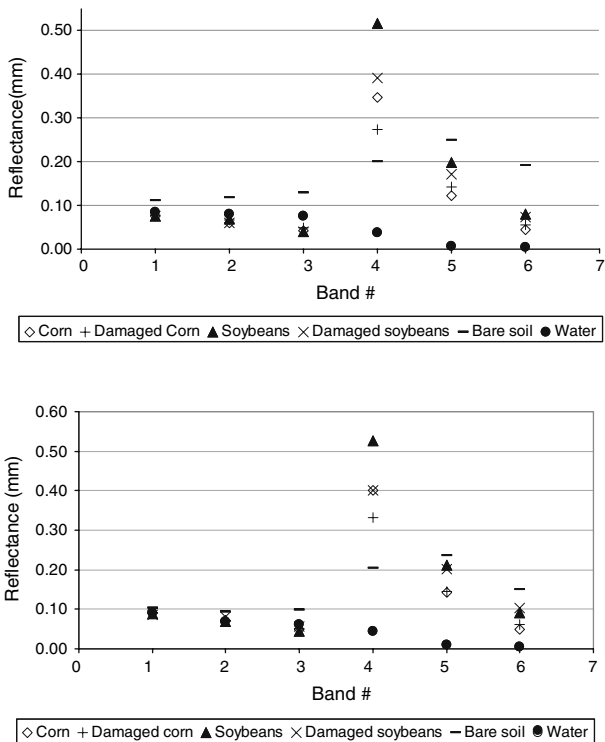
**Table 1** Threshold values for discriminating between damaged and healthy corn and soybean crops for the two Landsat scenes

|  | Threshold (μm) | |
|---|---|---|
|  | July 16th | July 25th |
| *Corn* | | |
| Band 4 (NIR) | 0.27 | 0.33 |
| Band 5 (Mid IR) | 0.14 | 0.14 |
| Band 7 (Mid IR) | 0.05 | 0.06 |
| *Soybeans* | | |
| Band 4 (NIR) | 0.39 | 0.40 |
| Band 5 (Mid IR) | 0.17 | 0.20 |
| Band 7 (Mid IR) | 0.05 | 0.10 |

## Results and discussion

We identified nine classes from the supervised classification: Corn, Damaged Corn, Soybeans, Damaged Soybeans, Bare Soil, Forest, Urban, Pasture, and Water. To quantify how good the map of nine classes was, a classification error matrix, also known as a confusion matrix or contingency matrix, was used to assess the accuracy. Table 2 shows the Producer's accuracy (that gives errors of omission, resulting when the pixel is omitted from its correct class), the User's accuracy (that gives errors of commission, resulting when a pixel is committed to an incorrect class), the overall accuracy (that is the number of incorrect observations divided by the number of correct), and the Kappa Index. The Kappa Index ($K$) is a measure of agreement that compares the observed accuracy to that expected by chance. A $K$ index of zero indicates the relation between the observed and expected values is due to chance, whereas a $K$ index of 1 indicates perfect agreement between the values. A Kappa value of about 0.8 is typically considered good (Landis and Koch 1977). The Kappa Index for the classification of the July 16th image was 0.76, and that for the July 25th image was 0.75.

### The flood plain

We selected a small section of the Wabash River to observe the direct impact of water flooding on crops. The water class obtained from the July 16th scene was used

**Table 2** Assessment of the accuracy of the supervised classification of the two Landsat images

| Class | July 16th | | July 25th | |
|---|---|---|---|---|
|  | Producer's accuracy[1] | User's accuracy[2] | Producer's accuracy | User's accuracy |
|  | 63.2 | 100 | 62.0 | 100 |
| Damaged corn | 100.0 | 90 | 98.3 | 90.0 |
| Soybeans | 86.7 | 100 | 90.7 | 100 |
| Damaged soybeans | 96.8 | 81.5 | 95.9 | 82.0 |
| Bare soil | 82.3 | 82.3 | 85.4 | 83.2 |
| Forest | 75.0 | 30.0 | 72.0 | 25.0 |
| Pasture | 14.9 | 25.0 | 17.8 | 27.1 |
| Urban | 71.4 | 71.4 | 70.3 | 70.3 |
| Water | 80.0 | 100 | 100 | 90.0 |
| Overall accuracy | 80.0 | | 79.0 | |
| Kappa Index | 0.76 | | 0.75 | |

[1] Omission error = 100–Producer's accuracy

[2] Commission error = 100–User'

to extract the area of the floodplain that was completely covered by water. This area was compared with the NASS land use maps for 2002 and 2003 (Table 3). In 2002, the NASS data indicated the floodplain was 50% pasture, whereas in 2003 it was almost entirely pasture (88%). This suggests that the crops were severely damaged and that grass and weeds emerged after the flood in much of the area.

Change detection matrix

A change detection matrix was used to compare the images from the two dates. It was not possible to analyze the conditions of the crops before the flood event as no images were available. The change detection matrix indicates the recovery of soybeans and corn over a period of about one week (Table 4). The threshold discussed previously was used for discriminating between healthy and damaged crops. Most of the soybeans remained in a damaged state; only 28.6% began to recover from the flood and the ponded water. Almost 50% of the corn improved in condition over the period. Small areas of both crops experienced further degradation: 6.3% of corn and 3.7% of soybeans. This is likely to be due to disease and insect damage. The stressed and weakened plants were more susceptible to disease and insects. Soybeans experienced more damage because: (1) they are generally more sensitive to changes in the environment, and especially to excess soil moisture; (2) the plants are shorter and smaller than corn, so more of the plant is under water; and (3) soil sticks to their leaves and prevents photosynthesis, causing further damage to the plant.

Corn was damaged less than the soybeans because it is more tolerant to environmental changes. By the middle of July, corn has reached the tassel stage, the roots are well developed, and plants are almost at full height (typically greater than 2 m), whereas soybeans are still at the bloom stage, which is the most critical in their development. Corn plants were tall enough to have their upper leaves above ponded water, enabling the plant to survive even if the lower part of the plant was either under the water or its lower leaves were dead. The tassel stage is critical for corn as

**Table 3** Comparison of the NASS land use maps over a selected segment of the Wabash Floodplain for 2002 and 2003

| Class | NASS 2002 | | NASS 2003 | |
|---|---|---|---|---|
| | Area (ha) | Area (%) | Area (ha) | Area (%) |
| Corn | 1,145.6 | 19 | 0.8 | <0.01 |
| Soybeans | 940.2 | 16 | 0.3 | <0.01 |
| Pasture | 2,873.5 | 48 | 5,310.0 | 88 |
| Woods | 443.8 | 7 | 29.0 | <0.01 |
| Urban | 305.9 | 5 | 7.8 | <0.01 |
| Water | 252.5 | 4 | 632.7 | 10 |
| Other crops | 19.6 | 0.3 | 2.1 | <0.01 |

**Table 4** Area of crops that improved, degraded or maintained stable conditions about a week after the end of the heavy precipitation

| | Stable healthy conditions | | Stable damaged conditions | | Improved conditions | | Degraded conditions | |
|---|---|---|---|---|---|---|---|---|
| | (ha) | (%) | (ha) | (%) | (ha) | (%) | (ha) | (%) |
| Corn | 49,539 | 27.2 | 31,089 | 17.0 | 90,057 | 49.4 | 11,471 | 6.3 |
| Soybeans | 20,625 | 9.3 | 129,656 | 58.4 | 63,564 | 28.6 | 8,289 | 3.7 |

the plants are susceptible to defoliation by strong wind (Morton et al. 2000); this did not occur in July 2003.

Delta NDVI

Delta NDVI was computed by subtracting July 16th NDVI values from those of July 25th. Positive values of Delta NDVI indicate an improvement in the conditions of the crops, whereas negative values show a deterioration of the vegetation. To identify which type of crop was associated with positive values, 1,000 points were extracted at random from the Delta NDVI image and plotted against the NASS land use classes (Fig. 5). Table 5 shows that most corn and soybean locations have a positive value (84% and 81%, respectively), indicating that the condition of the crop has improved slightly over the period of about one week. The magnitude of improvement is small given the small values of the Delta NDVI, which range from –0.035 to 0.10. Pasture and other types of crops have mostly negative values for this period.

Damage to crops, yield, precipitation and unharvested crops

At the end of the season, the damage caused by the flood and the heavy precipitation did not have a great impact on final yields (Table 6). The percentage of the area with corn and soybean damage decreased markedly between July 16th and 25th. It seems likely that crop conditions continued to improve because the yield for 2003 was approximately the same as the average of the mean yields for the period 1996 to 2002 for the six districts in the study. In fact, corn had a final yield greater than the previous six-year average. This was due in part to the drought that affected the yield for 2002 adversely. The area of corn reported as not harvested was very small, confirming that the impact of the flood was minimal on the final yield. The final yield
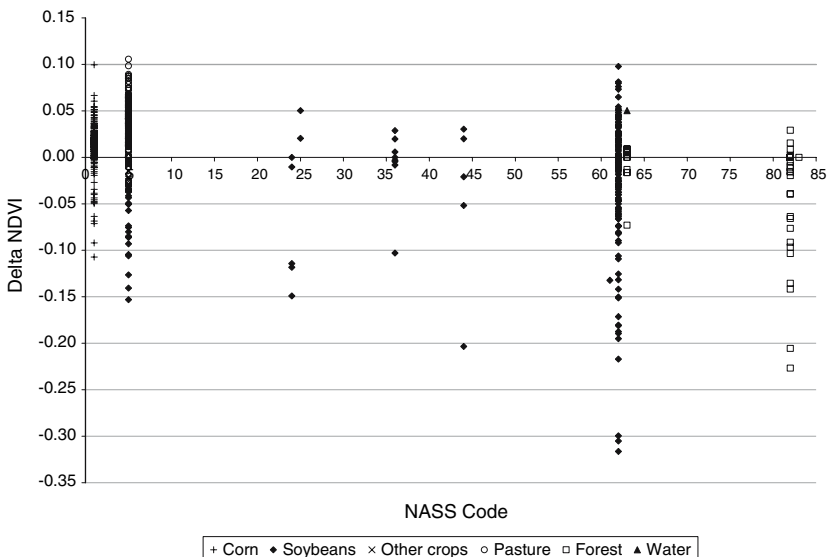


**Fig. 5** Delta NDVI values (*y*-axis) over the NASS 2003 land use classes (*x*-axis). The *x*-axis gives the NASS land use code for each category

**Table 5** Percentage of vegetation classes having positive Delta NDVI values in the area of overlap between the two Landsat scenes

| NASS 2003 classes | Delta NDVI values >0 (%) |
|---|---|
| Corn | 84 |
| Soybeans | 81 |
| Other crops | 43 |
| Pasture | 49 |
| Forests | 92 |

**Table 6** Percentage of damaged crops, final yield, mean yield, unharvested area and precipitation values for six Indiana districts

| District | Damage July 16th (%) | Damage July 25th (%) | Yield (t ha$^{-1}$) | Mean yield[a] (t ha$^{-1}$) | Unharvested area (ha)[b] | Precipitation (cm) |
|---|---|---|---|---|---|---|
| *Corn* | | | | | | |
| NW | 78.7 | 40.3 | 8.98 | 8.92 | 0.56 | 10.00 |
| NC | 52.8 | 39.3 | 9.29 | 8.60 | 0.35 | 13.30 |
| NE | – | 59.9 | 9.23 | 8.16 | 0.44 | 3.97 |
| Central | 59.9 | 41.8 | 9.36 | 8.79 | 0.75 | 12.31 |
| EC | – | 46.6 | 9.11 | 8.60 | 0.25 | 8.33 |
| WC | 63.4 | – | 9.61 | 8.35 | 1.13 | 7.76 |
| *Soybeans* | | | | | | |
| NW | 96.4 | 80.4 | 2.15 | 2.89 | 0.60 | 10.00 |
| NC | 86.5 | 73.0 | 2.36 | 2.96 | 0.33 | 13.30 |
| NE | – | 86.2 | 2.56 | 2.69 | 0.47 | 3.97 |
| Central | 85.1 | 79.7 | 2.76 | 3.03 | 0.80 | 12.31 |
| EC | – | 81.0 | 2.69 | 2.89 | 0.27 | 8.33 |
| WC | 96.0 | – | 2.49 | 2.89 | 1.21 | 7.76 |

[a] Average yield from 1996 to 2002

[b] Unharvested area = area planted–area harvested

of soybeans was only slightly smaller than that of the previous six years. The rate at which soybeans improve their condition after damage is typically slower than that of corn. For both crops, no significant correlations were found between yield, damage, and unharvested area.

The amount of precipitation was not an indicator of the damage to either corn or soybeans. On the contrary, the greater the precipitation, the less was the observed damage in this case; the correlation coefficient was 0.8. This result is different from what was expected and the reason might relate to soil properties, topography, and uneven spatial distribution of the rain over areas that are geographically distant. Water drains through soil at different rates depending on soil texture and composition, and on the slope of the land. Fine-textured soil drains slowly, whereas coarse-textured soil often drains rapidly. The mean suggests that precipitation values were equal throughout a district, which was not the case. The damage to crops was caused largely by localized ponding of water that depends on factors other than the amount of rainfall.

## Conclusions

The results of this study suggest that Landsat TM 5 is a suitable sensor for detecting damage caused by heavy precipitation and flooding over agricultural areas. The

Delta NDVI index is appropriate for quantifying the recovery rate of crops. However, images taken before a hazardous event and at the time of harvest would help in assessing the final damage. There was no significant correlation between the amount of rain recorded during the week of the flooding event and the amount of damage to crops. More detailed precipitation measurements and terrain data would help to improve our understanding of the relationship between these two factors. The final yield of the crops was not very different from the yields of the previous six years, suggesting that the flood and the ponded water affected the final yield only marginally for Indiana.

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