Freezing Damage of Winter Wheat in North China and Its Protection

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1. Overwintering ecological conditions in North China
2. Mechanism of freezing damage of winter wheat
3. Types of freezing damage of winter wheat in North China
4. Monitoring and prewarning of freezing damage of winter wheat
5. Protection from freezing damage
1. Overwintering ecological conditions in North China

1.1 Wheat mapping of overwintering

Winter wheat areas divided into 3 types:
Except north Xinjiang, due to continent monsoon climate, winter is very dry and cold in north China, almost no snow cover in some years. There is dry surface soil layer in the winter. The thicker the dryer soil layer is, the bigger soil temperature variation is.

<table>
<thead>
<tr>
<th>regions</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dormancy/frozen soil</td>
<td>stable</td>
<td>unstable</td>
<td>No</td>
</tr>
</tbody>
</table>
Regionalization of winter wheat (after И.А.Гольцберг 1972)
<table>
<thead>
<tr>
<th>dormancy</th>
<th>Cover Snow</th>
<th>Stable north</th>
<th>South</th>
<th>Unstable</th>
<th>no</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>North Xinjiang</td>
<td>N North China</td>
<td>M North China</td>
<td>S HHH Plain</td>
<td>Yountze valley</td>
</tr>
<tr>
<td>variety</td>
<td>Ext. strong winterness</td>
<td>Strong winterness</td>
<td>Medium winterness</td>
<td>Weak winterness</td>
<td>Weak winterness/springness</td>
</tr>
<tr>
<td>°C•d to winter</td>
<td>580-620</td>
<td>550-600</td>
<td>520-570</td>
<td>500-550</td>
<td>Can’t cal.</td>
</tr>
<tr>
<td>Frozen soil</td>
<td>60-100cm</td>
<td>40-70cm</td>
<td>20-40cm</td>
<td>&lt;10cm</td>
<td>No</td>
</tr>
<tr>
<td>precipitation</td>
<td>30-60mm</td>
<td>10-15mm</td>
<td>15-30mm</td>
<td>30-80mm</td>
<td>80-140mm</td>
</tr>
<tr>
<td>morphology</td>
<td>All leaves withered</td>
<td>Most withered</td>
<td>Base keep green</td>
<td>Leaf top withered</td>
<td>Active growth</td>
</tr>
<tr>
<td>drymatter</td>
<td>reduce &gt;1/2</td>
<td>-1/2 to1/3</td>
<td>Reduce little</td>
<td>Increase</td>
<td>Several times</td>
</tr>
</tbody>
</table>

Overwintering ecological conditions of winter wheat in different regions of North China
1.2 Why freezing damage in the North China is so frequent and severe

1. very few or even no snow cover days in the whole winter, tillering node often inside dry soil

2. due to lower latitude but near cold pole of the north semisphere in the winter, there is big temperature variation.

Therefore, North China is the most serious wheat area of winter freezing damage in the world.
Most years with big yield decrease due to serious freezing
2. Mechanism of freezing damage of winter wheat

2.1 main theories of plant freezing
- protective materials by Maksimov
- cold acclimation of wheat by Tumanov
- thermoperiod by F. W. Went or stage development theory in USSR;
- fause growth by Kubelman
- cell membrane injury by Lyons J.M., Levitt J., Li P.H. and Palta J.P.
- ice nuclei and supercooling of vegetation by Schnell and Vali
• LT50 model of freezing damage by W. Zheng

\[ P = \frac{1}{1 + \exp(aT+b)} \]

• \( P \) death rate of seedlings, \( a \) and \( b \) constants, \( T \) treating temperature at tillering node. LT50 lethal temperature with 50% death rate

• Temperate crops frozen inside cell.

• Due to special structure and protective materials, wheat cell sap dehydrates water into intercellular & frozen, protoplasm keeps supercooling. If temperature is very low or decreases too fast, ice crystal will cause cell mechanical injury.
2.2 Special freezing damage mechanism of winter wheat in North China

- Except injury mechanism by ice crystal, there are other two mechanisms of winter wheat in North China.
- Abnormal warming in the winter often causes cold resistant decrease.
- The intercellular water evaporated during winter due to drought. As a result, the cell swelling pressure cannot recover and the seedlings cannot revive.
### 3. Types of freezing damage of winter wheat in North China

3.1 Pattern of low temperature stress

- **Above 0°C:** chilling
- **Below 0°C:** frost, freezing (often confused)

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Frost</th>
<th>Freezing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Character</td>
<td>sudden</td>
<td>acumulated</td>
</tr>
<tr>
<td>Period</td>
<td>Active growth</td>
<td>In or near dormancy</td>
</tr>
<tr>
<td>Temperature</td>
<td>Near 0°C</td>
<td>Severe cold &amp; big variation</td>
</tr>
<tr>
<td>Damage Mechanism</td>
<td>Frozen inside cells</td>
<td>Frozen intercellular</td>
</tr>
<tr>
<td>resistant</td>
<td>losed</td>
<td>by aclimation</td>
</tr>
</tbody>
</table>
3.2 Freezing damage types in N. China

1. Violent temperature drop
   - Based on acclimation theory of Tumanov
     - Average T drops sharply from \( >5^\circ C \) to \( <0^\circ C \), and the Tmin reaches to \( <-8^\circ C \) in 1 to 3 days, resistant will be very weak due to lack of acclimation, even damaged in warm winter.

2. Long and severe cold winter
   - Freezing damage accumulated in the whole winter

3. Freezing after thawing
   - Early warming leads cold resistant lost & seedlings awaken, followed cold wave hurts seedlings.

4. Winter drought combining cold
   - More serious damage with many clods sna cracks
5. **Overdevelopment before winter**

- due to early sowing, warm autumn or springness varieties. leaves too long, seriously withered, fetter new leaves in early spring. central spike over differentialized and died.

6. **Unstable snow cover** only in N. Xinjiang

- In practise, often combines above 2 or 3 types. But most related with volent temperature drop in the beginning of winter.

- **Other factors** causing seedlings died: flood above frozen soil, snow injury, ice cover, frozen lifting, salination, pest, disease and eating by sheep, but the proportion is usually small.
3.3 Why freezing frequent as warming
Since 1980s winter warmer and drier in N. China
1. Difficult to breed varieties with strong hardiness and high yield. As winter warming, farmers always choose varieties with weaker cold hardiness and higher yield. LT50 of some varieties popularized round Beijing increased 2-3°C, and T in the winter only increased 1-1.5°C.
2. Warming makes soil dry and bigger T range.
3. Autumn warming caused overgrowth.
4. Bigger T fluctuation in the winter.
Negative degree-day in winter 1952-2000 in Beijing as climate warming

\[
y = -4.5262x + 396.77
\]

\[
R^2 = 0.3404
\]
Winter precipitation 1952—2000 in Beijing

\[ y = -0.2252x + 19.398 \]
\[ R^2 = 0.1094 \]
4. Monitoring and prewarning

1. Cold resistant index: LT50 by experiment
2. Suitable sowing date and quantity
   - based on relationship between degree-day and leaf age/shoot number
   - $Y=ax+b$, $x$--leaf age of main shoot, $Y$--degree-day from sowing to stop growth, $b$--degree-day from sowing to emergence, $80-100^\circ\text{C}\cdot\text{d}$. $a$--degree-day per leaf number, $80-90^\circ\text{C}\cdot\text{d}$.
   - $Z=\exp(ax+b)$, $Z$--shoot number per seedling, $x$--degree-day, $a$ and $b$ constants. $\exp(b)$ degree-day from sowing to tillering, $a$—tillering ability depends on seeds quantity, soil fertility and others.
   - The relationship will change to logistic function when shoot number becomes big.
Relationship between leaf age of the main shoot, shoot number pre seedling and degree-day from sowing
relationship between depth of sowing and tillering node

both deep & shallow sowing with higher death rate of shoots and seedlings
3. Acclimation before winter
   period of acclimation: T from 5°C to 0°C, >15 days satisfied. The longer the better.
4. T drops in the beginning of dormancy
   daily T drops >10°C and Tmin<-8°C, medium freezing; drop>15°C, serious freezing.
5. Winter coldness: negative degree-day
6. Winter drought
   thickness of the surface dry soil layer:
   Thickness >3cm >5cm >8cm >10cm
   effects light serious may die all die
7. Freezing after thawing

- Moving average T per 5d before cold wave and Tmin after cold wave

<table>
<thead>
<tr>
<th>T increase before cold wave (°C) and freezing damage</th>
<th>Moving T per 5d(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;0</td>
</tr>
<tr>
<td></td>
<td>&gt;3</td>
</tr>
<tr>
<td></td>
<td>&gt;5</td>
</tr>
<tr>
<td>Tmin after cold wave</td>
<td>Light</td>
</tr>
<tr>
<td></td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>-5</td>
</tr>
<tr>
<td></td>
<td>-3</td>
</tr>
<tr>
<td></td>
<td>Serious</td>
</tr>
<tr>
<td></td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td>-5</td>
</tr>
</tbody>
</table>

The warmer before cold wave and the deeper temperature drops after then, the more serious will be the freezing damage.
4.2 Morphology of freezing seedlings

1. Differences between freezing damage & drought

Winter drought: (1) unstable dormancy: shorter and less leaves, wither from bottom. (2) stable dormancy: dehydrate seriously.

Freezing: leaves soft/wet, wither/curl, dark green, gradually turn yellow.

2. Judging died or survival seedlings

Died seedling: tillering node profile dark and black

Died shoot: young leaf not emerged soft/wet/withered, or central spike muddy/withered

Overgrowing seedlings: wither/whole yellow, young tillers still survive. (Yellow not certainly died)

Fuse growth: green leaf weak stretch. checking tillering node. (green not certainly survival)
Upper:
Different varieties

Below:
Different seedling growth

1. health overgrowth

Weak due to late sowing

Weak due to deep sowing

Weak due to shallow sowing
Dry matter change from sowing to early spring in Beijing

By electronic microscope

Fause growth: dark node
Normal & frozen ear
Damage & normal young leaf not emergenced

Young leaf has not emerged is different to grow up due to cripming
Warm autumn caused overgrowth.

2005-2006

1980-1981
4.3 Prewarning based on disaster chain

Factors:
Preparation; sowing; acclimation; overwinter conditions; early spring; decision

Disaster chain and decision tree of freezing

- Strong: Very strong → No → No → Prevent lodging
- Medium: Strong → Light → Very few → Normal manage
- Weak: Very weak → Very severe → Heavy → After culture
- Very few: Some → More fertilizer
- Destroyed: Reculture crops
5. Protection from freezing

5.1 Principles of preventing

Based on systematic science, feedback

Feedback mechanism: A adverse resistant breeding; B cultivating health seedlings and acclimation; C improving field microclimate; D improving field ecological environment; E improving agricultural system; F adaptation ability of seedling
5.2 Two ways and three links

1. Improving micro environment: land preparation, irrigation before winter, compacting, harrow, cover, controlling pest and disease, windbreak

2. Strengthening cold resistant: resistant varieties, P & organic fertilizer, seeding time, depth & quantity, plant growth regulator.

Three links in different development stages:

1. Before winter dormancy: sowing quality & growing healthy seedlings;

2. Overwinter: protection from freezing, the key is to make soil enough moisture & a thin loose layer.

3. Early spring: remedial measures based on injury degree & seedlings ability of recovery.
5.3 Sowing quality & seedlings health

1. Preparation before sowing
   - land leveling/preparation, soil improvement, windbreak, resistant varieties, seed processing.

2. Determining suitable sowing date & seed quantity
   - Suitable density of seedlings/m² calculated by formula (2) and (3). 150-225, 300-400 and 600-675 for early, in time and late sowing respectively.

3. Suitable sowing depth and furrow sowing
   - Relationship between sowing depth x and depth of tillering node y as formula (4): \( y = \frac{x}{ax+b} \)
   - Safe depth is 2, 1.5, 1cm to the north of Great Wall, north part of the North China Plain, middle/lower reach and north of Huai River respectively.
Different varieties
Shangqiu
Mar.2005

seedling
jointed before
winter died

2009 Henan

2009 Beijing
• Furrow sowing is the best method combining advantages of deep sowing and shallow sowing.

5.4 Protection during winter

1. Irrigation in time
when <70% of field capacity, earlier in the sandy soil and later in the clay soil.
suitable time: temperature from 3°C to 7°C.

2. Coverage: soil, mud, organic fertilizer or stalk pieces

3. Compacting and light farrow

4. Irrigation to save seedings
dry soil layer is too thick, daily T>3°C.

Small quantity, otherwise flood or ice cover
Furrow sowing

Relation between sowing depth and leaf age, shoot number, fresh weight and secondary roots number.
5.5 Remedial measure in early spring

based on survival number and recovery ability

1. Overgrowing seedlings

almost withered and yellow. Most main shoots and big tillers died. But small tillers still survival and much nutrient store. Withered leaves should be raked up, irrigation and fertilizer should be earlier.

2. Weak seedlings

Water and nutrient absorb-ability is very weak. Firstly carefully loose surface soil and dressing P and organic fertilizer. After new roots emergence and further warming, irrigation and N fertilizer. Controlling weeds and pests.
3. Freezing damage combining winter drought
Compacting is the most important before soil thaw and become wet. If the surface dry soil layer is too thick, irrigation with small quantity should be earlier.

5.6 Reducing winter drought 2008-2009
Precipitation 70% to 90% less than normal years.
Three times strong cold wave in Dec. and Jan.
Typical disaster of freezing combining drought.
The Chinese Government organized farmers to rescue by compacting and irrigation in warm days with small quantity. Plus recent three times precipitation, most seedlings recovered now.
Best wishes for a rich harvest. Thank you.