一、黑龙江流域的重要性

《史记》有云“仓廪实而知礼节，衣食足而知荣辱”。在我们过着衣食无忧的小康生活的今天，极其恶化的问题更应成为我们重视的焦点。建国初期，经过战火的洗礼，全国上下百废待兴，当时的粮食问题当属第一，因此国家下令开发“北大荒”。“北大荒”泛指整个黑龙江流域，其主干河流黑龙江位于我国黑龙江省境内。黑龙江流域土壤肥沃，水资源丰富。肥沃的土地，丰富的资源，自然担负着国家粮食安全的重任。如今“北大荒”已经变成了年产千亿斤的“北大仓”。据黑龙江省第二次土壤调查数据显示，黑龙江省目前已经成为中国耕地面积最大的省份，人均耕地面积为全国均值的3倍以上。

图1 黑龙江三江国家级自然保护区（姜明 摄）
2015年黑龙江全省粮食播种面积为1176.52万hm²，全年粮食总产量达到6323.96万t。其中水稻的种植面积从19世纪80年代的21万hm²增加到2015年的314.78万hm²（东迎欣等，2009；康铁东，2014；国家统计局，2016）。
图1 黑龙江连片分布的水稻田（邱元春 摄）

在土地资源和水资源一定的前提下，耕地面积的增加意味着湿地面积的减小，农业用水的增加意味着生态用水的减少。近几十年来，由于水稻种植面积扩大，湿地消失成了一种普遍现象，在三江平原腹地的挠力河，竟然罕见地出现了断流的现象。

（一）黑龙江流域湿地与农业研究的现实需求

作为产粮重地的黑龙江流域，耕地面积在增加，而湿地的面积在不断地减小。由于我国农业水平不高，农民文化程度有限，致使农业生产中使用了大量的不合理且低效的农业生产模式。污水灌溉、化肥、农药、农膜等农业投入品的不合理使用及农业过度开发活动导致耕地土壤的破坏和湿地的严重污染（Zhang, 2010）。

根据《全国主体功能区划》，除了国际重要湿地、国家级自然保护区和国家级风景名胜区等属于禁止开发区外，在三江-松嫩平原，仅黑龙江省7个县（市）4.77万hm²纳入了限制开发的重点生态功能区，其余大部分都属于东北平原农产品主产区。在《全国湿地保护工程规划（2004~2030年）》中，三江平原已被列为国家湿地保护与恢复的重点区域。因此，必须首先协调好农业和湿地争水、争地的矛盾，才能实现天然湿地与农田的和谐共存。

为解决这一矛盾，就必须寻找出一个科学的可持续发展的农业生产模式，在耕地面积增加与湿地面积减少之间，在水稻种植面积增加、湿地消失趋势加剧之间，在提高粮食产量和湿地保护之间，寻求一个平衡点，来达到粮食需求和湿地环境保护的平衡。只有这样才能既保证粮食产
量上的需求，又能有效地保护湿地环境。因此本报告旨在对黑龙江流域粮食主产区现行农业生产模式进行有效评估，找出现行农业生产模式存在的问题和矛盾，分析现行农业生产模式对湿地造成影响的主要威胁因子，逐步推进现行农业生产模式的调查和评价工作，对农业模式对湿地的影响状态进行评估，提出有效的环境友好型绿色农业生产模式建议。该报告对于未来在黑龙江流域内建立可持续农业生产的长效机制，促进生态环境的恢复和人与环境和谐相处具有重要意义。

（二）黑龙江流域及流域中国境内湿地概况

1. 黑龙江流域概况

黑龙江流域（41° 45' ~53° 33' N，115° 13' ~135° 05' E）面积广阔，是世界第五大流域。该流域西起蒙古高原，包括蒙古、中国和俄罗斯的13个省及朝鲜的小部分（图5）。

图5 黑龙江流域示意图（杨伟，2013）

黑龙江流域面积约268 × 10^4 hm²，其中约有101 × 10^4 hm²在俄罗斯境内，89 × 10^4 hm²在中国境内，其余主要分布在蒙古境内。流域内人口分布极不平衡，总人口在70~80 × 10^4人之间，其中5 × 10^6人居住在俄罗斯，65~75 × 10^6人居住于中国境内，只有不到5 × 10^4人居住于蒙古境内（杨伟，2013）。中国境内的黑龙江流域主要在我国黑龙江省，内蒙古自治区，吉林省三省境内。东侧有长白山地，北部有小兴安岭，三列山地围成半圆形状，其内侧环抱三江平原和松嫩平原。
黑龙江流域的东部地区主要属于温带湿润季风气候，这是全球季风气候的最北缘，西部流域主要受大陆性气候的影响。流域全年平均气温在-8℃到6℃之间，但其时空分布差异显著。冬季1月份平均气温主要在-20℃到-32℃之间，但受鄂霍茨克海影响，东部太平洋沿岸的温度要高出10℃。夏季7月份整个流域平均气温在17℃到24℃之间，但沿海温度要低于内陆温度。流域年平均降水量主要在250-800mm之间，但流域内降水量的时空差异较大，大约50%以上的降水量集中在这炎热的夏季，而近7个月的气候（1-4月，10-12月）降水量仅为25%。在空间上，降水主要集中在沿海地带，向西逐渐递减（杨伟，2013）。

黑龙江流域水系以黑龙江为主干，主要支流有松花江、乌苏里江、嫩江等。该流域有地衣植物12科60种，苔藓植物67科419种，蕨类植物23科103种，种子植物117科2038种；有图目录动物2科36种，鱼类19科98种，两栖类6科13种，爬行类4科17种，鸟类382种，兽类21科104种（田鹏等，2007；崔茂欢，2006）。

2. 黑龙江流域湿地概况

在黑龙江流域有着大面积的湿地。现有天然湿地区面积达600万hm²，占黑龙江流域土地面积的6.63%。此外，还有人工湿地（水稻田）200万hm²，占黑龙江流域面积的2.21%（图6）。

图6 黑龙江流域湿地分布（左，1970；右，2010）

黑龙江流域天然湿地大致分布于五个地区，包括大兴安岭、小兴安岭及西部山区、长白山区、三江平原和松嫩平原地区。各区域面积如图7所示。
大兴安岭湿地：大兴安岭湿地包括内蒙古呼伦贝尔盟的全部，内蒙古大兴安岭森工集团的全部区域。主要有大兴安岭、呼伦湖、辉河地区、绰尔河流域、乌尔盖沼泽地区等，湿地面积为131.5万hm²。小兴安岭及东部山区湿地：包括嫩江一北安一哈尔滨线以北的整个小兴安岭。主要有呼玛河、逊别拉河、五大连池、汤旺河、兴凯湖、小兴凯湖、镜泊湖、莲花湖等，湿地总面积为115.5万hm²。

长白山区湿地：包括中长铁路以东，抚顺一宽甸线以北地区。主要是完达山、张广才岭以及黄沿的老爷岭和长白山腹地，以沙河、长春山自然保护区、松花湖、三湖自然保护区、水库、沿江和河溪等为主，湿地总面积为28.4万hm²。

三江平原湿地：由黑龙江、松花江和乌苏里江冲积的低平原与穆棱一兴凯湖及其湖积形成的低平原组成。包括完达山脉以北的三江平原和以南的穆棱一兴凯湖平原。主要是三江平原东北部、滨河自然保护区、七星河、沙河河流域、穆清河下游地区。总面积155.8万hm²，是我国湿地最集中的地区之一。

松嫩平原湿地：包括吉林通榆一乾安一伊通线以北的广大松嫩平原。主要有向海、莫莫格、扎龙、内蒙古科尔沁沼泽珍禽湿地、长吉沼湿地、图牧吉和龙沼沼泽地区，湿地面积为169.7万hm²（谭伟君，2004）。

（三）黑龙江流域湿地分类及功能

1. 湿地的分类

依据《湿地公约》中关于湿地的定义及湿地名录中的湿地分类系统，结合黑龙江流域湿地具体状况，将黑龙江湿地划分为四种类型：即河流湿地，湖沼湿地，库塘以及沼泽化草甸湿地（唐乃超，2009）。各类型湿地面积见图8所示（数据来自各省统计年鉴）。

![黑龙江流域不同湿地类型统计（单位:万hm²）](image)

黑龙江流域，主干是黑龙江，大小河流众多。上游较支流有盘古河、呼玛河、法别拉河等，下游主要支流有松花江、乌苏里江、莲花江等，因此有大量的河流湿地（郭彦超，2007）。

黑龙江流域还有众多的库塘以及天然湖泊，在湖泊和库塘周边，形成大面积的湿地。流域内，平原广阔，因而面积最大的属沼泽草甸湿地，面积达398万hm²。

2. 湿地的功能

在黑龙江流域有着众多的湿地资源。作为地球上重要的生态系统，湿地在地球的生态系统功能是无法替代的，其和海洋生态系统、森林生态系统共同形成了地球的生物圈。湿地具有极其丰富的生物多样性，在湿地周边生活着许多珍稀鸟类、植物以及鱼类（董崇智，1999；黄方等，2007；杨旭等，2005）。湿地是众多的生物赖以生存的空间，为动植物提供了充足的活动范围和食物来源，同时也为人类提供了食物、水资源以及一些生活所需的原料。湿地在抵御洪水、调节径流、控制污染、改善气候、美化环境等方面也起着重要的作用（谭伟君，2004）。此外，湿地还具有很强的人文经济功能，并为人类提供了观赏资源和重要的农副产品的经济资源（那守海等，2013）。湿地具体功能可概括为以下几方面：
生物多样性和动物栖息地：湿地是一个巨大的生物宝库（时萌等，2012）。无论是哪种类型的湿地，湿地的水流中，都含有较为丰富的营养盐和有机碎屑等大量的营养物质。这些在湿地周边生存的动物植物提供了生存的食物和肥料。因此，在湿地周围，生存着很多的鸟类，鱼类，两栖类以及兽类等动物。湿地为迁徙的鸟类，提供了越冬地场所。在中国湿地生活和繁殖的鸟类有300多种，占全国鸟类总数的1/3左右，我国一半左右的国家一级保护珍稀鸟类都生活在湿地。

图9 东方白鹳（Ciconia boyciana）（姜明 摄）

湿地具有净化水体降解污染的功能：湿地中，生长着各种微生物，浮游生物以及食腐的动物。微生物通过生物吸收，生物体内化学合成等分解作用，可以将湿地中的污染水，污染物等有害物质降解或转化。当带有污染的水体流经湿地时，就可有效的降解水体中的污染物，起到了净化水体的作用。

调节水量和局部气候：湿地是个天然的蓄水池，在暴雨和洪水来袭时，其可有效的蓄积洪水，降低洪峰的破坏性，起到蓄洪排涝的功效。枯水季节，湿地蓄积的水资源，又能很好的补给下游或周边的地区。湿地水分充足，与大气之间进行着广泛的热量交换和水分交换，所以在缩小昼夜温差、增加局部地区湿度、降低大气尘量等方面具有重要的作用。

社会经济功能：湿地具有很好的社会和经济效用。能够为人类提供丰富的渔业资源，水力资源。利用湿地的特性可以开发水生植物，水禽，鱼类以及家畜的养殖，为人们提供全面的农副产品。同时，湿地也是美的自然景观，可合理开发湿地保护公园，为人们提供观赏价值，带来一定的经济收入，对保护湿地也能做出很好的宣传（郭彦超，2007；黄洪武，2005）。
二、现有农业生产模式及其对湿地造成的影响与评估

（一）黑龙江流域农业生产模式

湿地生态系统，是地球上生态系统的重要组成部分，其功能和作用是其他生态系统无法替代的。由于大范围的农业活动，我国黑龙江流域的天然湿地大面积萎缩。农业活动对湿地的影响的主要原因就是不合理的农业生产模式。

农业发展至今，大致经历了传统农业、石油农业和现代农业几个阶段。传统农业指，在自然经济条件下，采用人力、畜力、手工工具、铁器等为主要的手工劳动方式，靠世代积累下来的耕作方法和技术进行的农业生产。而石油农业模式是指，以廉价石油为基础的高度工业化的农业的总称（刘兴等，2009）。现代农业则是指，依托现代先进的农业科学技术，采用可持续发展，绿色生态的手段进行的农业生产。而在黑龙江流域，早期的生产力落后，很大程度上仍沿用传统的农业耕作模式。虽然使用传统农业模式对环境破坏的程度很小，但是生产效率极其低下，无法满足人口增长所带来的粮食需求量。为增加粮食产量，黑龙江流域渐渐地从传统农业，转化到了石油农业，开始大量地使用农机和化肥农药。从粮食的产量上，确实满足了人们的需求，但石油农业带来的环境破坏，也是巨大的（张恩伟，2001；刘春，2014）。

三江平原的主要作物类型为玉米、大豆和水稻（Zhou & Liu，2005）。随着全球气候变暖，20世纪80年代以来，东北地区年均温增加了1.0-2.5℃（Yang et al., 2007）。1℃等温线的北移促进了东北地区水稻种植面积的扩大（Wang et al., 2009）。从1982年到2002年的20年间，由于水稻和玉米种植带北移了200~300hm，东北地区作物种植面积增加了8.6%（Yang et al., 2007; Lenz-Wiedemann et al., 2012）。
到目前为止，对黑龙江流域的农业开发已经持续50多年，虽然在粮食产量上取得了长足的进步。但是粮食高产的背后，依旧是落后的农业生产模式占主导地位。流域内，传统农业模式和石油农业模式并存（Luan et al., 2013）。

化肥农药的大量使用，以及高产作物的引进，都从一定程度上提高了粮食产量。对化肥的依赖及粗放式不科学的使用，导致过剩的化肥释放到环境当中，造成流域内地表径流污染，又形成大范围的面源污染。大量使用地下水，使地下水位下降，湿地枯竭，地面下降（刘兴土等，2000），对环境造成了不可逆的污染，对湿地生态系统的破坏更是严重（饶静等，2011）。由于湿地被大面积开垦利用，湿地面积不断缩小，污水净化能力不断降低，加上农业面源污染直接进入湿地，使湿地水质不断恶化（刘兴土和马学慧，2002）。

图10 农场水稻田使用农药（邬爱春 摄）
（二）农业水资源利用对湿地水文调蓄功能的影响与评估

湿地一般发育在地势较为低平的地形中，低洼的地形为湿地作为蓄水器提供了地势条件，同时湿地土壤容重小，空隙大，是蓄水防洪的天然“海绵”。据统计，全球约有96%的可利用淡水储存在湿地中，湿地是一个巨大的“生物储水库”。

湿地的蓄水量主要与土壤的持水量有关。沼泽土壤持水量一般比一般土壤高2~8倍。三江平原泥炭土和泥炭沼泽土表层饱和持水量高达6000~90000g/kg，腐殖质沼泽土和草甸沼泽土为1000~60000g/kg。由表层至底层，土壤的持水量逐渐降低（表1）（刘兴土和马学慧，2002）。以中国三江平原为例，沼泽和沼泽化土壤的草根层和泥炭层，孔隙度为72%~93%，饱和持水量为830%~1030%，最大持水量为400%~600%，每hm²沼泽湿地可蓄水8100m³左右，全区沼泽湿地蓄水量高达38.4亿m³。松嫩流域分布大面积的泡沼湿地和湿草甸，对减弱松花江和嫩江洪水分洪起到重要作用。以洮儿河和霍林河流域的湿地为例，1998年洪水期间，两河流域湿地总蓄积洪水达60亿m³，相当于大型水库的蓄水能力（刘兴土，2005）。平原沼泽湿地一般微地貌较为复杂，如在三江平原沼泽湿地中往往存在许多闭合的碟形洼地。当湿地地表水位上升到一定高程时，这些洼地中的水可能会发生水力联系，使得湿地既具有显性的蓄水空间，同时又有较大的隐性蓄水空间（吕宪国，2008）。

### 表1 沼泽土壤的持水量

<table>
<thead>
<tr>
<th>类型</th>
<th>深度(cm)</th>
<th>饱和持水量(g/kg)</th>
<th>毛管持水量(g/kg)</th>
<th>部分持水量(g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>草甸沼泽土</td>
<td>0~8</td>
<td>1240</td>
<td>1070</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td>8~16</td>
<td>930</td>
<td>750</td>
<td>440</td>
</tr>
<tr>
<td>湿泥沼泽土</td>
<td>0~10</td>
<td>1240</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10~20</td>
<td>690</td>
<td>490</td>
<td></td>
</tr>
<tr>
<td>腐殖质沼泽土</td>
<td>0~20</td>
<td>6100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20~30</td>
<td>5630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>泥炭沼泽土</td>
<td>0~20</td>
<td>8600</td>
<td>6080</td>
<td>4720</td>
</tr>
<tr>
<td></td>
<td>20~35</td>
<td>6420</td>
<td>5560</td>
<td>4480</td>
</tr>
<tr>
<td></td>
<td>35以下</td>
<td>600</td>
<td>330</td>
<td>310</td>
</tr>
<tr>
<td>泥炭土</td>
<td>0~15</td>
<td>9700</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18~37</td>
<td>8450</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40~55</td>
<td>6180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56~62</td>
<td>6540</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
湿地被开垦后，与土壤水文调蓄有关的物理结构发生了显著变化，土壤容重和比重增加，孔隙度降低（表2）（Wang & Yang, 2001）；毛管持水量、田间持水量、饱和持水量和最大吸湿量都随着开垦年限的增加而逐渐降低（表3）（Wang & Yang, 2001）。

### 表2 三江平原湿地开垦前后土壤物理性质变化

<table>
<thead>
<tr>
<th>土壤类型</th>
<th>深度(cm)</th>
<th>饱和持水量(g/kg)</th>
<th>毛管持水量(g/kg)</th>
<th>田间持水量(g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>天然沼泽</td>
<td>0-8</td>
<td>0.59</td>
<td>1.82</td>
<td>74.4</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>0.80</td>
<td>1.99</td>
<td>67.3</td>
</tr>
<tr>
<td>开垦2年</td>
<td>0-8</td>
<td>0.74</td>
<td>2.13</td>
<td>69.4</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>0.87</td>
<td>2.17</td>
<td>65.1</td>
</tr>
<tr>
<td>开垦7年</td>
<td>0-8</td>
<td>0.90</td>
<td>2.24</td>
<td>64.6</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>1.11</td>
<td>2.30</td>
<td>59.0</td>
</tr>
</tbody>
</table>

### 表3 三江平原湿地开垦前后土壤水含量变化

<table>
<thead>
<tr>
<th>土壤类型</th>
<th>深度(cm)</th>
<th>毛管持水量(%)</th>
<th>饱和持水量(%)</th>
<th>田间持水量(g/kg)</th>
<th>最大吸湿量(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>天然沼泽</td>
<td>0-8</td>
<td>106.5</td>
<td>123.6</td>
<td>85.2</td>
<td>10.30</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>74.7</td>
<td>92.8</td>
<td>44.1</td>
<td>8.66</td>
</tr>
<tr>
<td>开垦4年</td>
<td>0-8</td>
<td>45.6</td>
<td>53.7</td>
<td>32.7</td>
<td>7.36</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>55.8</td>
<td>69.4</td>
<td>41.3</td>
<td>8.30</td>
</tr>
<tr>
<td>开垦7年</td>
<td>0-8</td>
<td>50.2</td>
<td>58.4</td>
<td>29.7</td>
<td>6.06</td>
</tr>
<tr>
<td></td>
<td>8-16</td>
<td>44.5</td>
<td>54.9</td>
<td>28.8</td>
<td>6.46</td>
</tr>
</tbody>
</table>

湿地补水功能主要表现在补给地下水和补给河川径流。湿地往往与区域地下水含水层有直接水文联系，特别是在深层地下水与湿地水文常常发生相互补给渗透的关系。处于不同地貌部位的湿地，对地表水和地下水的影响也不同。当湿润的水位高于周围陆地潜水面时，就会产生地下水补给，如果湿地的水位高于周围潜水面，地下水就会流出湿地。季节性积水的湿地或多或少都依赖于地下水，地下水和地表水存在明显的相互补给关系，尤其是地下水对湿地具有重要的顶托作用，地下水位的变化明显影响湿地生态系统。
沼泽水分补给地下水的方式有直接补给和间接补给。直接补给是指水分通过沼泽土壤直接渗透进入含水层；间接补给是指水分首先水平运动通过土壤进人位于可渗透性的土壤或河流，然后通过河流基底补给地下水。

湿地与地下水除了水量上相互补给渗透之外，湿地区域内地表水和地下水化学特征间的水力学联系也十分紧密。在扎龙湿地中，受湿地地表水的影响，浅层地下水具有典型的二元循环模式，地下水中间的氮、磷主要来源于地表水的输入而非土壤的垂直淋溶作用。湿地湖泊水和河流水均为中等矿化度的HCO₃-Na型水，而地下水类型则由HCO₃-Ca·Na·Mg型转变为HCO₃-Na·Ca型（王磊和赵光新，2007）。

湿地对部分河川径流具有重要的补给作用，特别是被平原区沼泽性河流，直接决定其径流量。黄河上源在流经属于若尔盖湿地的玛曲湿地后，径流量增加超过100亿m³，因此若尔盖湿地起到青藏高原“中华水塔”等的重要涵养功能，并对黄河中下游地区生态具有举足轻重的影响。

湿地补水功能，受到多方面因素的影响，如湿地土壤持水量、渗透性、孔隙度等。同时湿地利用方式、蒸发强度和水文情势的变化也间接影响湿地的补水功能。湿地的开发往往会造成当地地下水位降低，如湿地受到破坏或消失，就无法为地下水层供水，地下水资源就会减少。

农业开发对地下水位的影响十分显著。自20世纪80年代以来，三江平原地区大面积沼泽被垦为耕地，减少了沼泽对地下水的补给量，增加了对地下水的开采量，导致地下水位连续下降，区域地下水位普遍下降3~4m，一些水稻种植区水位下降十几米（尹元等，2000）。玉门平原的前进、创业、八五O等农场1999年地下水位远低于1997年分别下降了2.61m、0.94m和0.11m，与之同时对应的水稻田面积增加到39%~127%（刘兴立和马学慧，2002）。王喜华（2005）选取了近河地区（距离河道3~5.5km以内）22眼观测井，远河地区/非灌区（>5.5km）12眼观测井以及灌区14眼观测井的地下水平面数据，利用泰森多边形法分别求得了3种主要地区的地下水埋深平均值。三江平原地下水埋深总体上呈下降趋势，不同地区变化程度不一样。近河地区，由于河流与浅层地下水补给联系密切，相互补给作用频繁，使得地下水埋深在2008~2012年间以0.27m/a的速率下降。对于灌区，由于大量的开采地下水平面进行灌溉，灌区回水率远小于开采量，使得地下水水位埋深下降速率较大，在2008~2012年间以0.80m/a的速率下降。对于近河/非灌区，没有河流的卡面水的补给作用，也没有开采大量的地下水平面行灌溉，因此在2008~2012年间以0.56m/a的速率下降。
图11 利用地下水灌溉水田（郭元春 摄）

湿地调节径流和均化洪水功能与湿地土壤和植被等结构特征密切相关。湿地土壤的特殊水文物理性质，使得洪水被储存在土壤内或以表面积的形式保存于湖泊和沼泽中，这直接减少了下游的洪水量。一部分洪水可在数天、几星期或数个月的时间内从储存地排放出来，一部分则在流动的过程中通过蒸发和下渗成地下水而被排除。此外，湿地植被能够增加地表粗糙度可减缓洪水流速，避免了所有洪水在同一时间到达下游，降低下游洪峰的水位，并使之平稳缓慢下泄，能够有效地分散、消解洪水带来的巨大能量。这两种过程降低了下游洪峰的水位，延长洪水在陆地存留时间（图12）。

图12 湿地调节径流示意图（吕光国，2006）
三江平原挠力河流域上游宝清站与中游菜咀子站之间发育大面积沼泽湿地，湿地率达32.7%。河流洪泛时，由于大量洪水在河漫滩沼泽中漫散和蓄存，沼泽的蓄水滞洪作用使菜咀子站的夏季洪峰流量值减小50%（相对流量），并使汛期向后推迟（刘兴土，2007）。

图13 三江平原挠力河流域宝清站与菜咀子站（实测）洪峰流量对比（刘兴土，2007）

三江平原原有34000km²沼泽湿地。随着几十年来大规模开发北大荒，三江平原相继建起了34个国家农场，使湿地全部镶嵌在大型现代化农场群的耕地之中，尤其是20世纪90年代以来，以稻治涝、大规模发展水田、强排强灌等水利设施的盲目上马，使湿地地表水疏干和地下水位下降十分严重，湿地内储存的100多亿m³地表水减少了87亿m³（蒋升阳，2004）。三江平原200多条湿地性河流出现萎缩、干涸，4000多个泡沼缩小或消失，湿地水、地表水、地下水相互循环与转化的独特系统被打破。根据朱开山等（2014）基于遥感影像的结果分析表明，从1976年到1986年，三江平原湿地面积下降了38%，到1995年又下降了16%,到2005年，进一步下降了31%。从湿地转变为农业用地占湿地损失的91%，而转变为草原和森林仅占湿地损失7%。政策体制和市场政策对农业活动的调节直接或间接影响了湿地的减少。

由于三江平原近年来的大规模“旱改水”，大量的旱地被转变为水田，因此，旱田的土壤含水量呈下降趋势，而水田则逐渐增加；作为单位面积土壤含水量最高的生态系统类型，三江平原沼泽湿地的历年平均土壤含水量仅为4.4×10³m³，这主要是由于多年的大规模农业开
垦造成该地区沼泽湿地几乎消失殆尽，尽管分布面积仅占整个平原区的4.97%，其保存的土壤水却依然占到总量的8.4%。

图14 三江平原近15年来土壤含水量比率

湿地如一座巨大的水库，在维持水均衡和生态平衡中发挥着强大功能。三江平原湿地是天然的自然珍宝，没有替代，一旦破坏便不可复制。因此需要通过修建筑坝、退耕还林还草、建保护区、搬迁村屯农场、完善水利体系等措施，保证湿地生态用水，恢复和重建沼泽湿地，珍惜保护和合理开发利用三江平原总量有限的地表地下水资源。

（三）沟渠对湿地的影响与评估

水是湿地最重要的影响因子。水量的多少将直接影响到湿地生态系统的动态平衡及其功能的正常发挥，缺水是导致湿地退化的关键原因（吕宪国，2004）。所以水对湿地的影响是非常重要的，它直接影响着湿地的生物与分布，决定了区域物种和群落，制约着湿地的种类和湿地的分布情况。
现有的农业生产模式中，开沟造渠、旱田改水田是一种重要的农业手段。人们依托河流、天然湿地，大面积的挖沟排水，开渠造田。沟渠是一种人为的产物，它具有输水和排水两种作
用。沟渠的出现，已经完全改变了自然的水文格局，使湿地的水量输入和输出、天然水体滞留时间发生多方面的改变，因而对湿地系统的发育、演化具有重要作用。

图15 宽阔笔直的干渠（邹元春 摄）

我们以三江平原为例，据黑龙江统计年鉴统计，到1986年，已开挖主河道116hm；开挖支河、总排干渠76条，长700多hm，兴修支、斗、毛渠1600多条，长4000多hm；修建各种桥、涵、闸、强排站820座，防洪大堤2座，总计完成土方量6200多万m³。到1991年，三江平原就已经完成旱田改水田293.65万Mu，增加灌溉面积293.95万Mu，增加除涝面积1003.97万Mu。修建小型水库23座，修造排灌站215座，打机电井18407眼。

从数据和湿地观察中，我们可以分析出，天然湿地已经被人工水稻田所分割，天然湿地散落在稻田的周围，湿地稻田间由大量的沟、渠相连，沟渠增加了湿地的水体流通。天然环境下的湿地，其水体流通是相当缓慢的，所以可以起到很好的水源涵养作用。而与沟渠相连通以后，其水体快速的沿着沟渠排向了径流当中，导致了湿地的水量不能得到保证，湿地因沟渠的排水而导致缺水，甚至干枯。

我们根据最新的黑龙江垦区水利图集，利用ArcGIS对三江平原的沟渠进行数字化处理，得到现有三江平原沟渠图（图16）。
从图16当中，我们可以清晰地看出，沟渠网络相当密集，而且已经形成巨大的规模，湿地与沟渠大部分重叠，或者湿地镶嵌于沟渠网络之中。沟渠构成的人工湿地极大地改变了天然湿地的诸多特性。天然湿地与人工湿地共同形成了新的湿地系统。这些湿地沟渠不仅打破了该地区原有的地貌格局，还改变了湿地之间自然的水文联系，形成了新的水文格局。在这种水文格局控制下，湿地中蓄存的水量在不断减少，其生态系统处于极度的不稳定状态，且湿地在逐渐退化，导致地区环境质量在不断下降，严重地威胁了湿地物种的生存甚至湿地的存在，同时加重了湿地景观破碎化的程度，阻碍了地区资源环境可持续发展（佟守正，2012）。小三江平原由于近几十年的农业开发活动导致了湿地水位的巨大变化，排灌渠系和防洪堤的建设干扰了洪泛平原的动态变化，日益减少的洪泛平原面积导致洪峰值量和径流的增加，导致湿地的丧失和破碎化，对湿地群落和生物多样性产生了巨大影响（刘海玉等，2004；Chen et al.，2014）。
成片的沟渠网络，在很大范围和程度上，变成了人工控制的状态，演变成为了天然水文循环系统之内的人工支循环系统（王浩等，2005）。沟渠密度是衡量流域通达性的一个重要指标，就流域湿地而言，沟渠密度越大，其通达性也越大（佟守正，2012）。三江平原地区沟渠总长度为24368.4hm，按整个平原区面积10.88×10⁴hm²计算，沟渠指数为0.22hm/hm²；按低地貌地区面积7.78×10⁴hm²计算，沟渠指数为0.31hm/hm²。结合图16、17分析可知，三江平原地区，各县境内沟渠分布的情况差异较大，其中，沟渠长度最大的为虎林市，为3404.5hm；其次为同江市，长度为2880.3hm；再次为宝清县，长度为2872.5hm。但是，沟渠指数最大的为友谊县，指数为0.75hm/hm²；其次为同江市，指数为0.47hm/hm²；再次为虎林市，指数为0.37hm/hm²。

通过对三江平原23个行政单元不完全统计资料（黑龙江红星总局水务局，2010）的相关分析发现，沟渠长度与湿地损失面积之间呈极显著的正相关关系（r=0.929，p<0.001），沟渠密度与损失面积之间也呈显著的正相关关系（r=0.655，p=0.001）。根据线性回归，沟渠长度可以解释86%的湿地面积损失，从线性回归方程可以看出，沟渠长度每增加1km，湿地将损失面积0.01km²（图17）。

![图17 三江平原沟渠长度与湿地损失面积关系](image)
除了对湿地分布和面积的影响，沟渠还会影响残留湿地的物质平衡。沟渠系统的沉积通量显著高于天然湿地，而且在沉积物的组成上各沟渠间也有显著差异：前者的泥沙占绝对优势，而后者以枯落物为主。流通量的变化还引起了一些元素的物理和化学变化。各级沟渠和天然湿地沉积物中的总氮含量没有显著性差异，但铁氧化物及其组成已发生了改变，并导致了一些元素的流失，如氮、磷等元素的含量（苏文等，2015）。另有研究表明，排水沟渠的修建改变了湿地土壤可溶性有机碳（DOC）的释放过程和迁移路径（郝敏，2007）。

（四）不合理的开发对湿地面积的影响与评估

我国是个人口大国，拥有全球1/6的人口。巨大的人口数量，随之带来了巨大的粮食需求。因此，建国初期开始，我国对黑龙江流域进行了高强度的农业垦荒。以黑龙江流域的三江平原为例。大规模开荒前，垦荒面积为82万hm²，开荒面积大约占三江平原总面积的7.53%。
由于当时开荒面积较少，当地仍然保持着较为原始的形态。仍然可见大面积的湿地（谭伟君，2004）。随着新中国的建立，人口不断地增长，经济不断地进步，粮食的需求也成指数倍增长。自20世纪50年代末开始，三江平原进入了急速发展的时期。与此同时，黑龙江流域的其它地区也进行了大规模的开发，如扎龙湿地，松花江流域湿地，也都遭受到了很大程度的破坏（Na et al., 2015）。

从20世纪50年代至今，黑龙江流域的三江平原共经历4次开发高潮：第一次是1949-1960年，12年间，开垦耕地72.7万hm²，土地垦殖率上升到了13.9%。但当时，由于新中国刚刚成立，机械化程度低，开发速度较慢，对湿地的影响，还不是特别的巨大；第二次从60年代初至1977年，将近20年的时间里，耕地面积由原来的72.7万hm²迅速增长到212万hm²，土地垦殖率上升至19.5%。70年代中期，三江平原还保持着相对于原始的景观；第三次是从1978-1985年，此期间由于农业机械化的进一步提升，导致在此期间，耕地面积迅速增至297.3万hm²，土地垦殖率达到27.3%。到1980年耕地面积达到311万hm²，沼泽和沼泽化草甸湿地面积已减少到220万hm²；第四次是从80年代中期到现在，在此期间新开垦农田173.3万hm²，使全区耕地面积达到473.3万hm²，土地垦殖率增至43.7%（赵魁义等，2008；宋开山等，2008；Zhou et al., 2005）。近50年来大规模开发北大荒，三江平原建成了52个国营农场，使湿地镶嵌在大型现代化农场之中，形成了湿地斑块化的景观（施建敏等，2010）。

三江平原的七星河湿地，从1954年至今的面积变化很具有代表性，成为三江平原湿地面积变化的缩影。人们为了发展生产，大面积开发农田，外加人口大面积扩张，需要更多的居住地，都很大程度的侵占了湿地的面积，导致七星河湿地面积锐减。1957年七星河湿地的面积为3.62×10⁴hm²，到2000年面积仅剩2.00×10⁴hm²（于宏敏等，2014）。由于近几十年的农业开发活动，小三江平原地区在1950-2000年约有73.6%的湿地丧失，大规模土地开垦带来的自然湿地和森林快速转化为农业用地，不仅使得湿地面积严重减少，自然湿地和生境丧失破碎化，还对许多赖以生存的动植物物种造成巨大影响（刘红玉等，2004）。

据黑龙江省统计年鉴以及土地资源调查等相关数据，我们绘制了三江平原地区耕地面积变化图，如图19所示:
从图中可以清晰直观的看出，三江平原，从建国初期开始，连年开发，耕地面积持续增长。尤其是到了1975年以后，增速更为突出。如此快的耕地面积增速，也清晰地反应出湿地的面积在迅速地削减。

在20世纪90年代，由于黑龙江政府采取了一些不合理的政策，过于追求粮食的产量，提出“再建一个北大荒”的口号。由此致使三江平原的湿地又进一步的减少。从80年代的199.7万hm²，减少到1998年的155.8万hm²（王宗明等，2009）。

2000年开始，黑龙江省更是加大了大型机械的使用。短短的十年间，单农用大型拖拉机就增加了近80万台。农业模式从手工转变为大型机械，尽管加快了农田的开发速度，但致使湿地的面积成指数性减少。具体数据如表4所示。
表4 主要农业机械拥有量（黑龙江省年鉴）

<table>
<thead>
<tr>
<th>年份</th>
<th>农机总动力 (1000kW×10%)</th>
<th>农用大中型拖拉机 (台)</th>
<th>小型拖拉机 (台)</th>
<th>大中型拖拉机配套农具 (台)</th>
<th>小型拖拉机配套农具 (台)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1613.8</td>
<td>75553</td>
<td>65.2</td>
<td>19.2</td>
<td>62.8</td>
</tr>
<tr>
<td>2001</td>
<td>1648.3</td>
<td>78177</td>
<td>65.3</td>
<td>18.9</td>
<td>64.6</td>
</tr>
<tr>
<td>2002</td>
<td>1741.8</td>
<td>85266</td>
<td>68.0</td>
<td>19.4</td>
<td>69.4</td>
</tr>
<tr>
<td>2002</td>
<td>1741.8</td>
<td>85266</td>
<td>68.0</td>
<td>19.4</td>
<td>69.4</td>
</tr>
<tr>
<td>2003</td>
<td>1807.7</td>
<td>99462</td>
<td>69.5</td>
<td>20.1</td>
<td>76.3</td>
</tr>
<tr>
<td>2004</td>
<td>1952.2</td>
<td>127795</td>
<td>71.6</td>
<td>22.2</td>
<td>83.6</td>
</tr>
<tr>
<td>2005</td>
<td>2234.0</td>
<td>217275</td>
<td>74.4</td>
<td>31.9</td>
<td>87.7</td>
</tr>
<tr>
<td>2006</td>
<td>2570.6</td>
<td>323087</td>
<td>75.5</td>
<td>40.9</td>
<td>104.5</td>
</tr>
<tr>
<td>2007</td>
<td>2785.3</td>
<td>381813</td>
<td>75.7</td>
<td>47.2</td>
<td>110.3</td>
</tr>
<tr>
<td>2008</td>
<td>3018.4</td>
<td>491795</td>
<td>71.4</td>
<td>59.3</td>
<td>113.2</td>
</tr>
<tr>
<td>2009</td>
<td>3401.3</td>
<td>583015</td>
<td>71.1</td>
<td>67.4</td>
<td>117</td>
</tr>
<tr>
<td>2010</td>
<td>3756.3</td>
<td>654789</td>
<td>9.3</td>
<td>75.9</td>
<td>118.1</td>
</tr>
<tr>
<td>2011</td>
<td>4097.8</td>
<td>732577</td>
<td>68.8</td>
<td>92.7</td>
<td>120.2</td>
</tr>
<tr>
<td>2012</td>
<td>4549.3</td>
<td>808875</td>
<td>66.5</td>
<td>104.5</td>
<td>119.6</td>
</tr>
<tr>
<td>2013</td>
<td>4848.7</td>
<td>873322</td>
<td>64.5</td>
<td>118</td>
<td>118.5</td>
</tr>
</tbody>
</table>

图20 农场使用拖拉机犁地（邹元春 摄）
松花江是黑龙江流域的重要支流。其周边湿地是黑龙江流域湿地的重要组成部分。从流域大规模开发以来，松花江流域湿地也遭到了严重的破坏。湿地面积萎缩，建设用地面积扩张，林地保留率相对较高。其中，湿地—耕地、耕地—建设用地的转化较为剧烈（曹慧明等，2014）。表5显示了从2000年到2010年间，松花江全流域土地利用类型变化。

表5 松花江全流域土地利用类型变化（曹慧明等，2014）

<table>
<thead>
<tr>
<th>流域</th>
<th>一级地类</th>
<th>2000年</th>
<th>2005年</th>
<th>2010年</th>
</tr>
</thead>
<tbody>
<tr>
<td>全流域</td>
<td>耕地</td>
<td>23.56</td>
<td>23.63</td>
<td>23.79</td>
</tr>
<tr>
<td></td>
<td>林地</td>
<td>22.94</td>
<td>22.92</td>
<td>22.86</td>
</tr>
<tr>
<td></td>
<td>湿地</td>
<td>4.22</td>
<td>4.09</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>草地</td>
<td>2.80</td>
<td>2.80</td>
<td>2.77</td>
</tr>
<tr>
<td></td>
<td>建设用地</td>
<td>1.46</td>
<td>1.52</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>其他</td>
<td>0.63</td>
<td>0.64</td>
<td>0.59</td>
</tr>
</tbody>
</table>

由于湿地的斑块化，湿地的分布呈零星状，零散分布于各个农田的周边。生境破碎化造成生物栖息地丧失、生境面积减小或生境隔离，从而直接或间接地导致物种组成改变、降低物种多样性，湿地生态功能丧失（施建敏等，2010）。

根据吴运军、张树文等人的研究：2000年与1954年相比，旱地日益连通，破碎化指数下降了96.43%；沼泽地的面积则日益减少，其破碎化程度越来越高。近五十年，在乌苏里江流域的农业开发，表现为林地、湿地面积减少，破碎程度增加，乌苏里江水土流失效应增强（吴运军等，2006）。

虽然后来人们逐渐意识到湿地对生态的重要性，建立了诸多的湿地保护区，禁止个人非法开垦湿地。但由于一些农户的文化水平较低，并未意识到法律的存在，以及湿地保护的重要性，加之巨大的利益驱使下，使得在一些湿地周边，依然存在着农户私自开垦湿地的情况。以上因素致使湿地面积仍然逐年减少，外围向中心逐渐缩小。

对已开发的农地，利用率不足。现有已开垦的农田，如合理利用运用科学的农业生产模式，可使其亩产量进一步提高。但现有农田大部分利用率在75%左右。在未达到充分利用土地的情况下，又盲目地开垦新的农地，造成了农田的资源浪费。现有农田利用不合理，又盲目地开垦，造成了农田与湿地争地的状况。
（五）传统农业生产模式对湿地水环境的影响与评估

人类土地利用活动是自然水体水质变化最重要的影响因子（Niu et al., 2013）。而对于城市废水、工业污水所造成的点源污染，由于近几年政府加强了这方面的认知和管理，已经得到了很好的改善。而对于农业用地，农业生产中使用的化肥，农药所造成的非点源污染，引起的水体污染管理和控制，较为困难（贺维生等，1998）。对于区域水环境的管理应主要集中在控制农业面源污染方面（Baker et al., 2003），而导致严重的农业面源污染的影响因子，则是不合理的农业生产模式。

由于农业生产中，大量的人为活动以及大量过度的不合理的使用化肥，导致黑龙江流域内，地表水污染严重（田坤，2006；闫伟，2008；NIU et al., 2013）。

以嘉荫县为例，表6中列出2001-2005年的监测数据，污染参数和污染指数。

表6 黑龙江干流（嘉荫段）主要污染指标统计（田坤 2006）

<table>
<thead>
<tr>
<th>项目</th>
<th>溶解氧 DO</th>
<th>氨氮 NH₄⁻-N</th>
<th>亚硝酸盐氮 NO₂⁻-N</th>
<th>氰化物 Cyanide</th>
<th>六价铬 Cr⁶⁺</th>
<th>镉 Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl₀（污染参数）</td>
<td>3.0</td>
<td>1.5</td>
<td>1.0</td>
<td>0.2</td>
<td>0.2</td>
<td>0.005</td>
</tr>
<tr>
<td>Pij（污染指数）</td>
<td>2.787</td>
<td>17.71</td>
<td>0.014</td>
<td>0.01</td>
<td>0.01</td>
<td>0.4</td>
</tr>
</tbody>
</table>

从表6中可以清晰看出，本地区河流污染物主要以有机农药氰化物、硫化物、汞、铬为主。而这些污染物的主要来源是农业生产中的化肥农药。

化肥的使用，尤其是氮肥的输入，将导致氮素流失，污染地表水体。氮肥利用率低，施入土壤中的氮肥只有30%-50%被作物吸收利用，其余通过挥发、反硝化和淋失等过程损失掉。氮肥施入土壤后，淋溶损失、地面径流冲刷和随水流流失到环境中去，大部分进入地表水体（丁迎欣等，2009）。2005年，黑龙江因农业造成的水污染造成的经济损失就达到了62.76亿人民币（闫伟，2008）。因此农业造成的水污染的代价是巨大的。改变现有的农业模式，使得化肥农药用量减少，减轻农业造成的水体污染迫在眉睫。
因地表水受到污染，无法灌溉农田。现有农业模式又大量开采地下水进行灌溉，造成了地下水位的连年下降。据统计，黑龙江垦区三江平原地下水年可开采总量为30.14亿m³，目前年开采量已达31.62亿m³。严重的超采开地下水，已导致此地区地下水位逐年下降。

近年来，由于大面积的旱田转水田。使得农业生产用水量加大，又进一步地加大了地下水的开采。根据黑龙江省统计年鉴，截止至2013年农用排灌动力机械统计，如图22所示：

图22 农用排灌动力机械统计（黑龙江统计年鉴）

图22中方块折线和圆圈折线代表了农用排灌的柴油机和电动机，可以看出，从2000年开始至2013年间，农用排灌机械的数量是在逐步提升的。这也从侧面的反映出了地下水开采的增加。
二、现有农业生产模式及其对湿地造成的影响与评估

黑龙江省全省，从1980年至2013年间，水稻种植面积从21万hm²增加到40万hm²。为了可以清晰地看出水稻占粮食总产量的比例，根据黑龙江省统计年鉴数据，绘制了百分比堆积柱状图（图23）。

图23 1980年-2010年黑龙江省水稻种植面积变化（黑龙江省统计年鉴）

图23中深灰色柱状图百分比代表水稻占粮食总产量的百分比。从图中不难发现，水稻的种植面积比例在逐年攀升。黑龙江省近20多年来，尤其是2005年到2013年期间，水稻种植面积更是成倍增长，比最初的水稻种植面积增加约20倍。

以三江平原为例，全区水田面积已由1983年的9.2×10⁴hm²发展到1996年的53×10⁴hm²以上，而且还有继续扩大的趋势。洪河农场有耕地面积1.86×10⁴hm²，1992水稻种植面积仅有72hm²，1996年水稻种植面积已扩大到1.12×10⁴hm²，占该农场耕地面积的60.2%；前进农场的水稻种植面积也由1991年的100hm²增加到1996年的1.03×10⁴hm²，增加100倍（中国工程院“东北水资源”项目组, 2006）。
合理的早田改水田具有很高的价值，但由于我们的早田改水田不是有效地利用地表水，而是用机电井大量的抽取地下水，用地下水灌溉稻田后，所用的水大部分从排水渠流走，只有极少量的水渗入地下，极大浪费了地下水资源，严重地破坏了地下水的稳定结构，因此造成了大面积的湿地干涸（宁金荣等，2004）。不合理的早田改水田能够引发湿地蓄水量下降，导致湿地因缺水而干枯。周边流经的黑龙江、松花江、乌苏里江年过境水量达到2785亿m³，没有得到合理的利用，白白流走（康百赢等，2003），地下水的水质也受到了不同程度的污染，如松花江，其浅层地下水普遍也受到了污染，其中三江平原IV、V类水质面积占15%；松嫩平原IV、V类水质面积约占28%（中国工程院“东北水资源”项目组，2006）。

![图24 早地改水稻田（郭元春 摄）](image)

修建堤坝，是导致湿地萎缩的又一重要原因。近几年来，在黑龙江流域修筑起了大大小小的堤坝和水渠，截止到1980年，黑龙江流域就已修建大型水库19座，中型水库119座，小型水库1734座，已建电站8座（康百赢等，2003）。将本来流经湿地的水拦截，湿地因此供水不足，导致退化。一些水利工程的建立，又隔断了自然河流与湿地之间的联系，挖沟排干湿地的水，致使湿地萎缩，直至消失（Zhou et al., 2009；张国春，2007）。
（六）现有农业生产模式对土壤环境的影响与评估

一直以来，我国农业一直秉承着“天人合一”的思想，强调人与自然的亲和，共生及一体性关系（胡火金，2002）。合理协调，高效用地，采用合理的作物种类组合布局，轮作复种、间作套作，合理密植等措施进行综合协调（彭世荣，1990）。作物轮作导致土壤轮耕，从而优化了作物群体之间以及作物与土壤之间的生态关系（胡火金，2002）。从黑龙江流域大规模开发以来，这些宝贵的经验却没有得到延续，取代之的是大规模的石油农业生产模式。

养地是为了保持土壤的活力，使土地可持续利用（徐军，2009），而不至于过度耕种导致肥力下降，土壤盐化、沙化，致使土壤水土流失。黑龙江省的黑土、黑钙土的垦殖率已经分别达到74%和72%。多年投入少，广种薄收，粗放经营，致使肥力大幅度下降。投入产出持平耕地仅占14.8%，75.2%的耕地投入少或极少。黑土地开垦20年的肥力下降1/3，开垦40年的下降1/2。土地贫瘠加剧了土壤物理性质的恶化，致使土壤板结，黑土的性质发生了变化，导致土壤含水量下降（郑荣，2010），低产田面积增大（李保国，2014）。

改革开放后，我国人口成指数倍增长，带来了巨大的粮食需求。建国初期，由于农业科技水平较低，而人们又迫切的需求粮食，过于追求粮食的产量，而完全忽视对环境的保护，实施了大量违反自然违反规律的农业生产。土地的使用没有用养结合，肥力下降时就大量使用化肥。越来越单一化的作物。没有作物轮种，致使黑龙江流域的土地遭到了很大程度的污染和破坏，引发了一系列严重的生态问题，如土地贫瘠化，土壤盐渍化土壤结构肥力变化，土壤水含量减少等一系列生态问题（赵春兰等，2006）。

<table>
<thead>
<tr>
<th>样地地点</th>
<th>层次</th>
<th>有机质</th>
<th>全氮</th>
<th>全磷</th>
<th>钾</th>
<th>速效氮</th>
<th>速效磷</th>
<th>速效钾</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(g/kg)</td>
<td>(mg/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>290农场</td>
<td>0~20</td>
<td>59.50</td>
<td>2.60</td>
<td>1.30</td>
<td>29.40</td>
<td>440.90</td>
<td>191.60</td>
<td>262.00</td>
</tr>
<tr>
<td>24队</td>
<td>20~40</td>
<td>4.60</td>
<td>0.40</td>
<td>0.60</td>
<td>30.90</td>
<td>249.40</td>
<td>65.70</td>
<td>68.00</td>
</tr>
<tr>
<td></td>
<td>0~20</td>
<td>6.41</td>
<td>0.42</td>
<td>0.20</td>
<td>2.67</td>
<td>54.6</td>
<td>22.69</td>
<td>57.17</td>
</tr>
</tbody>
</table>
从表7中可以很清晰的看出，在垦荒30年后，黑龙江省两个农场的土壤氮磷钾等营养元素的含量均有大幅度的下降。这就是建垦初期至今，对土地重用轻予的结果。


<table>
<thead>
<tr>
<th>年份</th>
<th>农药使用量（万t）</th>
<th>年份</th>
<th>农药使用量（万t）</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>3.10</td>
<td>2005</td>
<td>4.75</td>
</tr>
<tr>
<td>2002</td>
<td>3.54</td>
<td>2006</td>
<td>5.20</td>
</tr>
<tr>
<td>2003</td>
<td>3.66</td>
<td>2007</td>
<td>5.79</td>
</tr>
<tr>
<td>2004</td>
<td>4.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
表9 1997-2005年黑龙江省农药使用水平变化趋势（kg/hm²）（马军韬，2009）

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.98</td>
<td>3.06</td>
<td>3.06</td>
<td>3.16</td>
<td>3.10</td>
<td>3.59</td>
<td>3.73</td>
<td>4.77</td>
<td>4.71</td>
</tr>
</tbody>
</table>

从表8、9中可以清晰的看出，黑龙江省的农药使用水平在逐年增加，使用量在逐步增大。根据黑龙江省统计年鉴显示，截止到2013年，黑龙江省使用化肥总量为5.78万t，与2007年使用量基本持平。说明近年来，绿色有机农业进程开展的较为顺利，但还有很多不足。

松花江是黑龙江流域的重要支流。由于松花江流域周边的农田大量的使用化肥，造成了松花江流域严重的面源污染。松花江流域农田化肥折存量161万t，农药使用量5.6万t（李博，2012）。最终受污染的水体，一并汇入了黑龙江干流，加重了黑龙江干流的污染程度。

在农业生产活动中，化肥的不合理施用，导致氮、磷等营养物质，农药残留物及其他有机或无机污染物质，通过农田的地表径流和农田渗漏进入水体，造成水环境的严重污染（孟宪科等，2011）。目前，农业上施用的化肥主要是氮、磷、钾3种，但是由于施用量不当及施肥不合理，常使很多化肥被浪费掉，而且随水土流失进入水体，从而加剧了环境污染，导致生态系统多方面失调，造成河流及地下水源的污染。虽然大量的施用化肥，但一些植物所需元素仍然无法补偿。黑龙江省松嫩平原粮食主产区土壤缺氮面积占87.9%，缺磷面积占46.1%，缺钾面积占72.4%，缺硫面积占86.1%，缺锌面积占61.3%，缺硼的面积占43.6%（李玉铭等，2010）。据有关资料表明，农田径流带入地表水体的氮，占人类活动排人水体的氨的51%，施氮肥地区氮流失比不施地区高3-10倍。农田化肥的大量无节制使用和大面积流失，对流域水质影响较大，是难以控制的薄弱环节。据调查，目前我国每hm²土地使用的化肥已超过400kg，而化肥的利用率仅为40%，大量化肥随着农田径流进入了河流。

中国曾经大量的使用过有机氯农药。而有机氯物质在环境中不易降解，其在水体中的半衰期从几天到20年不等，有的甚至达到100年。土壤中的半衰期为十年左右，个别
可达到500年之久。有机氯对人体的危害极大，它可以导致人类免疫系统受损，诱发癌症等（姜安玺等，2004）。

虽然我国很早停止了有机氯农药的生产和使用。但是之前大量的使用，仍然在土壤中有残留。对黑龙江流域（中国）采集的土壤样品中的六六六和滴滴涕浓度进行分析结果表明，黑龙江流域（中国）土壤中六六六浓度的平均值为$1.057 \times 10^{-3} \text{mg/kg}$，浓度范围为$0.0037 \times 10^{-3} \text{mg/kg}$~$9.82 \times 10^{-3} \text{mg/kg}$，滴滴涕浓度的平均值为$0.87 \times 10^{-3} \text{mg/kg}$，浓度范围为$0 \times 10^{-3} \text{mg/kg}$~$6.11 \times 10^{-3} \text{mg/kg}$，均低于长江三角洲地区、广州地区和天津等地区土壤中六六六的浓度。

自1952年至1984年黑龙江流域（中国）六六六的总使用量为108.9kt，自1951年至1984年滴滴涕的总使用量为4.9kt。由于黑龙江流域（中国）内的作物主要种植于松嫩平原和三江平原，农药的使用也主要集中于这些地区，因此在流域内黑龙江省六六六和滴滴涕的使用量最大，其次为吉林省，内蒙古自治区使用量最小。

2005年黑龙江流域（中国）土壤中六六六和滴滴涕的排放量较刚停止六六六和滴滴涕使用的1985年下降了很多，且主要集中在三江平原和松嫩平原及其附近的主要区域内，除个别区域外，北部山区和东南部山区排放量几乎为零（刘丽艳，2007）。

从短期的利益上看，农药的大量使用确实增加了粮食的产量。可从长远的眼光来看，其做法严重的破坏了自然生态平衡，使得生态系统中一个重要的组成部分的湿地遭到了严重的破坏。
三、湿地与农业和谐发展的建议

大面积开垦，大兴水利工程，大量的工业化产品如化肥、农药、杀虫剂等广泛用于农业上，来获得农作物的高产。从粮食的产量上看，确实在逐年增加，大量丰富的农产品，满足了人们对食物的迫切需求，但同时也造成了资源的浪费、生态环境的破坏以及产品质量的低劣。因此高污染、高浪费的旧的农业生产模式应被摒弃，而需要开发出一种环境友好型的绿色生态农业生产模式（姚延峰等，2014）。生态农业是利用生态学原理，依据生态系统内物质循环和能量转化的基本规律建立的一种农业生产方式，具有整体、协调、循环、可持续性特点，有利于实现经济、社会、环境三大效益。应充分利用现代及未来新能源、新材料、新装备以及新技术、新生物技术等武装起来的农业高新技术体系与生产模式，目的就是在确保生态环境友好的前提下，通过提高农业科技内涵和提高农业生产管理水平实现农业产业的高值化，最终大幅度提高农业生产能力、产品化水平、竞争力和比较效益。生态高值农业包括生态农业及环境与农产品高产、高质、高效及科技、市场、产业经济价值相结合的方面（章家恩等，2005）。

黑龙江流域农业开发与湿地保护之间尚存在一定的矛盾，二者的矛盾不利于区域生态安全和整个生态系统服务功能价值最大化，也严重制约了该区湿地生态功能的发挥。从粮食安全角度考虑，耕地面积应保持一定规模；从维护区域生态安全、生态服务功能角度考虑，湿地的面积应保持上升的趋势。因此，应在黑龙江流域建立一种环境友好型绿色农业，在保证粮食产量的同时应尽量增加湿地面积，遏制面积萎缩和功能退化，具体几点建议如下：
（一）制定完善的湿地保护法律法规并加强宣传

完善的政策和法规是有效保护湿地和实现湿地资源可持续利用的关键。建立行之有效的湿地管理政策对于该地区湿地资源的保护和合理利用有着十分重要的意义。为此要评估现行政策和现有法规在该区湿地保护中的作用，及时建立和完善与湿地有关的政策和法规，并在国土资源利用的经济运行机制下，逐步建立和完善鼓励并引导人们保护与合理利用湿地、限制破坏湿地的经济政策体系。要以法律法规的形式，明确各湿地管理机构的权限和管理分工，并规范其管理程序。此外，该区还应重视发挥媒体、群众团体和研究机构等的舆论宣传和监督作用，在不断提高公众保护意识的基础上法律归根结底是行政上的手段（孙志高等，2006）。为了让人们真正意识到湿地的重要性，自己建立起保护湿地的意识，才能更好的保护湿地，需要政府及相关部门，加大宣传力度，不断强化人们对湿地的认识与认知，并定期开展宣传课程，让人人参与其中，才是长久之计。在黑龙江流域，在大力贯彻实施相应的法律法规的同时，还应该大力宣传湿地保护的重要性，同时增加湿地保护区域的数量和规模，保持生物多样性，对不适合开垦地带退耕还湿，建立合理的资源环境生态水利体系，保持一定的湿地规模（李静等，2009）。

（二）农业开发与湿地保护要均衡

湿地保护，不是大面积的退耕来增加湿地的面积。由于我国的粮食需求还很大，黑龙江流域又作为全国的商品粮重要基地，承载着很多的压力与重任。但是粮食生产又不能盲目的乱开发，乱开垦，即使短时期内粮食产量增加，可从长久的利益来看，盲目开发过后，环境逐渐恶化，使得现有土地大面积沙化，盐碱化，土壤肥力下降，势必也会导致粮食的减产。因此，在协调好粮食生产及湿地保护两者关系基础上，应该加大对湿地保护的科学研究，成立专门的研究课题小组。针对合理的湿地开发，进行深入的研究，以达到开发利用与生态保护的良好平衡点。当前三江平原湿地面积缩小，地表水流失严重，致使生态环境恶化。鉴于三江平原湿地在维持区域水均衡和生态平衡中发挥着强大功能，亟需开展修筑堤坝、退耕还林还草、建保护
三、湿地与农业和谐发展的建议

区，完善水利体系措施，保证湿地生态用水，恢复和重建沼泽湿地，珍惜保护和合理开发利用三江平原的资源。20世纪70年代末到80年代初这一时期的农业生产生产的湿地环境是比较协调的，该时期三江平原农作物播种面积和湿地面积分别为870×10^4 hm²和195×10^4 hm²，其中湿地面积相当于建国时三江平原湿地面积的37%，在此恢复目标下，按照物种多样性和生境面积的幂指数关系，三江平原湿地的植物种类数和鸟类种类数可分别恢复到建国时水平的70%和80%。由此可见湿地恢复带来的生态效益十分显著（严冬等，2006）。

（三）大力开展生态种植

生态农业模式，其最重要的一点就是用养结合，提高利用率。据调查显示，已被开发的农田当中，有很大一部分土地的利用率极低，未能对已开发农田进行很好的利用，使得农田变成了低产田。而实际上，每亩农田的产量，在实施生态农业后，在原有基础上，还可以有很大的提高和进步。所以，需要以科学的方法和手段，实施生态农业，合理利用现有资源，而不是盲目开垦新的土地。土地的用养结合很关键，过度的耕种会使土地肥力下降，造成土地沙化以及水土流失。

秸秆还田这种种植模式，是一种典型的生态种植的模式。根据生态学原理，只要有非生态成分，生产者和分解者这些基本成分，就可以构成一个生态系统（冯伟等，2012）。如若按传统的种植模式，粮食收割后，秸秆被焚烧处理的，这样极大地破坏了空气环境，使得东北地区每逢农业收割的时间段，空气质量指数急剧下降。如果将秸秆堆起田处理，秸秆可以成为年的农作物提供充分的养料，使得元素得到充分利用，改良了土壤的养分，降低化肥的使用量，还能很好地避免了秸秆燃烧造成的空气污染。

黑龙江流域，现有的农业生产模式当中，另一很大的问题就是农作物过于单一化。当年的以稻治涝的决策，虽然有效地防止了因夏季降雨过量导致的涝田，但并不是一个万全之策。以稻治涝虽解决了一些问题，可随之而来的就是农作物单一化，对土地的消耗过大，因此需要让作物多元化立体化。在已有的资源内，实现立体的综合的，农产品输出。立体生态农业，就是利用生物之间的相互作用，互利共害，为了充分利用空间，把不同生物种群组合起来，多物种共
存，多层次配置，多级物质能量循环利用的立体种植、立体养殖或立体种养的生态农业经营模式。例如，桃子—草莓的立体化栽培、黄瓜—苦瓜立体种植、西瓜—彩椒立体种植、韭菜套种黄瓜等（王志平，2011；韩东峰等，2008）。这样不但使土地利用率大大提升，不再由于单一作物，对土地单一化的元素摄取过量。而且在空间上也得到很好的利用，从地面作物到顶层作物，很好的使用了空间，节省了土地。

对于大量的使用工业化肥这种农业模式，是非常不可取的。大量的使用化肥不但会对环境造成污染，同时喷洒农药化肥的时候，也有大量的有害成分残留在农作物上，又给食品安全造成了威胁。为解决这样的问题，完全可以开展食物链种植模式和沼气生态种植模式。该模式可以大大缓解工业化肥的使用，转而使用更为绿色的生物化肥，这样既降低了环境污染，又能保障生产出来的农副产品的绿色健康。这种模式的基本原理在于依据生态系统的能量流动规律，以及物质的循环规律为基础思想，建立起的种植模式。例如，粮—猪—沼—鱼模式（王志平，2011）。我们知道种植水稻的田地里是有一定量的水，我们完全可以利用稻田中的水，来养殖鱼类，或者虾类。鱼类产生的粪便自然就是水稻最好的肥料，而水稻产生的稻壳又可以喂猪喂鱼，猪产生的粪便还可以进行沼气发电。如此的循环模式，各个环节所产生的废料，又被合理的利用起来，使原本还需花费金钱和精力去处理的废物，又产生了巨大的价值。这种模式以沼气发酵为纽带把养殖业和种植业联系起来，沼气作为能源，沼液和沼渣作为肥料，使生态系统走上了良性循环的道路（刘红梅等，2010；陈豫等，2010；骆世明，2009）。

黑龙江流域由于受江河流域及封闭半封闭地形的影响，常年渍水或季节性渍水的湿地资源十分丰富。但由于北方湿地资源开发利用的历史较晚和指导思想上的以旱作为主，采取排水治涝、克湿旱种等措施，使得北方地区湿地农业发展缓慢。为了科学而有效地开发和利用这一地区的湿地资源，探索湿地农业生产的内在机制和高效低耗的综合发展之路，中国科学院东北地理与农业生态研究所于19世纪80年代在黑龙江省海伦市百发村进行了湿地湿生农业生态模式的研究，建立了“稻—草—鱼—牧”复式结构模式，并对其能流、物流、水份和养分循环以及经济效益等进行了研究，取得了较理想的成效，为相似气候带的湿地农业开发和整治，提供了一定的理论依据和实践经验。东北北部平原湿地资源不同经营方式的生态经济效益有显著差
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异。湿生系统优化的机理是生物与环境相协调和主副组生命体生产与消费形成链环，提高了能量转化效率与物质循环的速度，增加了经济效益（韩晓增等，1990）。2003年以来，中国工程院院士刘兴土带领的科研团队对严重退化的荒漠化土地进行生态恢复与合理利用研究与示范，并应用生态学的生物共生与物质循环原理，建立苇－鱼（蟹）－稻复合生态工程模式，取得了显著的经济和生态效益。恢复后的芦苇湿地和重度盐碱地改造后的水稻田可以为鱼、蟹提供饵料资源，鱼、蟹可摄食与芦苇争肥争空间的杂草和危害芦苇的害虫，鱼、蟹的粪便可增加肥源，其摄食活动又可疏松土壤，促进芦苇地下茎发育繁殖，从而提高芦苇的质量与产量。而且苇田中大量的沉水植物还为鱼、蟹提供良好的繁殖、避敌场所。

（四）建立农业示范县

建立生态农业示范县，首先最直观的影响就是可以大大提高示范县的农业生产模式水平，极大的促进生产力，有效的带动当地的经济水平。其次，通过建立农业示范县可以起到宣传、引导、示范的作用。农业示范县的建立，六要以身作则的实施发展生态农业，还要带动周边的县，农场达到全面生态农业，实现以农业示范县为核心，带动周边县，农场全面实施生态农业的目标。如广东地区多个生态农业的建设，使得农场果树覆盖率达到50%，十里果树，远远飘香，一副生机盎然的景象。生态示范县的建立，还要以示范县为中心，建立强大的宣传能力，和教育能力，使得广大农民了解生态农业的益处。在宣传生态农业的同时，还可以开展一些其他的创新课堂，以提高农友们们的素质。如第一批生态农业示范县在1994—1998年期间，共举办各类培训班1120次，培训人员16万人次（丁颖，2008）。通过这些学习和培训，极大地提高了农民的农业水平，使得生态农业技术，无师自通。现有生态可以改善农民的生活水平。如京山农民在生态农业建设过程中，劳动者素质得到显著提高，农村致富领域由低层次向高层次拓展。全县已有1000多名农民获得初、中级技术职称，有1/3的农村劳动力掌握了1—2门多种经营实用技术和生态农业知识（丁颖，2008）。

（五）开发新农技，改善湿地农业生态系统管理水平

为发挥湿地农业生态系统功能的基础，需要加强对湿地农业生态系统的研究，制订出湿地的农业综合开发和合理利用的策略，以及保护湿地物种资源和水土资源的策略，建立合理的湿
地农业生态结构，促进湿地农业生态系统的发展。建设和发展湿地农业生态系统，既要依靠合理的宏观决策，制定综合发展规划，也要不断发展适应自然、经济和社会条件下的湿地农业生态系统管理技术（房建，2003）。为更好地为湿地农业保护与管理提供科学依据，需加强湿地农业资源保护与合理利用的基础和应用技术研究（刘红梅等，2010），积极探索湿地农业保护、修复和可持续利用的示范模式，加强科技支撑，特别要重视开发各种生物资源利用技术、发展各种有利于减少外部物质投入、保持系统稳定和持续的生态技术，以及相应的提高农业生产率的技术。此外在黑龙江流域，还必须进一步加大对湿地资源合理利用的科研力度，改进已有的湿地生态系统模式，完善和创建优质高效的生态农业模式（姚允龙和吕宪周，2008）。

（六）促进湿地与农业和谐发展

湿地与农业的和谐发展，可以为我国生态和粮食安全提供坚实保障。我国在湿地与农业的和谐发展方面，一直有着很好的范例。例如，珠江三角洲等地的果基鱼塘、桑基鱼塘等种养模式（钟功甫，1980；韩晓等，1990），湖泊湿地渔业生产的放苗增殖模式，南方稻田中稻-鸭、稻-渔等立体生态种养殖模式，湿地自然保护区正在探索的核心区季节性保护管理模式等。此外，由于湿地资源功能独特，在开发、利用和保护湿地的过程中，发展特色农业可以实现湿地价值的充分利用，可充分发挥其间接使用价值，使湿地资源的保护与利用和谐起来（梁山等，2009）。充分利用自身湿地生物资源优势，不断完善湿地农业经营模式，建设区域特色的复合生态系统经营模式，能够增加湿地农业和生态系统的多样性（杨青等，2001）。因此在推进生态文明建设，坚持节约资源和保护环境的基本国策基础上，应探索并实施湿地与农业和谐发展模式，积极尝试特色农业生产，不断完善湿地农业经营模式，为当地人民创造良好生产生活环境，并为全球生态安全作出贡献。
总结

纵观黑龙江流域的湿地变化，大量的农业活动以及不合理的农业生产模式对湿地生态系统造成了严重的破坏。湿地是地球重要的生态系统，是大量动植物的栖息地。而人口增长对粮食需求的不断的增加，农业用地和湿地用地之间产生了矛盾。一方面，不能单纯追求农业的高产，导致对湿地及环境的巨大破坏。另一方面，保护湿地还需要保证粮食副产品的需求，不能简单的退耕还地。因此要加大科学研究，科学投入，找到一种切实可行的平衡的办法，使得既可以最大程度地保护湿地，又可以保证对粮食的需求。为合理协调农用地利用、粮食生产与环境保护的矛盾，在保证生态环境不恶性循环的前提下发展经济，合理控制湿地农田化过程与规模，建立可持续发展的湿地生态农业对保障粮食安全、实现湿地资源合理开发利用和保护具有重要的意义。因此，在黑龙江流域开展环境友好型的绿色农业生产模式势在必行。该生产模式可以提高效率，对自然环境的影响可以降到最低，并通过良性地循环，使湿地得到更好的保护。
参考文献


Abstract

Wetland, a habitat for many rare birds, fish, and plants, is one of the important ecological systems worldwide. Wetland plays an important role in the global ecology and is recognized as the "kidney of the earth." The Amur River Basin is an important wetland because of its conservation area. Large-scale reclamation, agricultural activities, and unscientific modes of agricultural production have caused great damage to the natural wetlands in the Amur River Basin since the foundation of the People's Republic of China. To date, an accurate environment-friendly agricultural production mode has not been implemented in the basin. Therefore, existing agricultural production mode in the Amur River Basin must be comprehensively assessed.

The Amur River Basin is one of the most important basins in China and has created wetlands of different sizes because of its wide catchment area. This basin also provides abundant land, wetland, animal, and plant resources. Existing agricultural production activities in the Amur River Basin have caused serious threats to its ecological environment. In this regard, we performed several investigations and analyses on the Amur River Basin. Issues regarding agricultural production activities and factors influencing the natural ecological environment of the wetland were defined. The effects of agricultural activities were also evaluated in many aspects.

We considered several factors to solve the contradiction between agricultural development and natural wetland conservation and comprehensively analyze the problem. We also investigated the effects of water utilization, canalization, pesticides, and fertilizers on the wetland environment. Canalization was identified as the main cause of the loss of natural wetlands. Model assessment indicated that the ditch increments of the Sanjiang Plain were positively correlated with the natural wetland loss, which means water resource is the key issue of the conflict between agricultural development and wetland conservation.

The influences of agricultural activities on wetlands were determined by assessing the main contradictions and providing suggestions to establish a new type of wetland-friendly green agriculture. Consequently, the wetland ecological environment and agricultural production would not be contradictory and could be coexist. We hope that this report could contribute to enhancing the protection of wetlands in the Amur River Basin, through facilitating the communication of stakeholders of wetland protection and agricultural development.

Keywords: Agricultural production mode, sustainable development, wetland conservation, Amur River Basin
1. Importance of the Amur River Basin

In the early years after the foundation of the People’s Republic of China, several issues need to be addressed because of the effects of war. At that time, the main problem is food source. Therefore, the state ordered the development of “the Great Northern Wilderness,” which refers to the Amur River Basin, the main river in Heilongjiang River located in the territory of Heilongjiang Province. The Amur River Basin is rich in soil and water and is responsible for the national food security because of its abundant land and resources. Currently, “the Great Northern Wilderness” has become “the Great Northern Barn”. According to the Second Land Survey of Heilongjiang Province, Heilongjiang Province possesses the largest arable land area in China, with the arable land area per capita 3 times more than the national average.

Fig. 1. Sanjiang National Nature Reserve (Photo by Mr. Ming Jiang)
In 2015, the grain-sown area in this region was $1.176.52 \times 10^4 \text{hm}^2$, and the total grain output reached $6323.96 \times 10^4 \text{t}$. Moreover, the rice-planting area increased from $21.0 \times 10^4 \text{hm}^2$ in 1980s to $400 \times 10^4 \text{hm}^2$ in 2015 (Dong et al., 2009; Kang, 2014; National Bureau of Statistics of China, 2016).
Under the premise of land and water resources, the increase in arable land area indicates the decrease in wetland area; similarly, the increase in the level of agricultural water suggests reduction in the amount of ecological water. Wetland water shortage has become a common phenomenon because of the expansion of rice-planting area in recent years. In particular, the Naoli River, which is located in the hinterland of the Sanjiang Plain, dries up infrequently.

1.1 Practical demand of wetland and agricultural research in the Amur River Basin

The Amur River Basin is a major grain-producing area, with a large cultivated land but small wetland. Considering the low agricultural level in China, the education level of farmers is limited; as such, agricultural production uses a large amount of unreasonable and inefficient agricultural production modes. The irrational use of sewage irrigation, fertilizers, pesticides, and other agricultural inputs as well as the activities of excessive agricultural development have caused the destruction of farmland soil and severe pollution of wetland (Zhang, 2010).

According to the national main function zoning, in addition to the areas such as international wetlands, national nature reserves and national scenic spots are not allowed to be developed. Most of the other counties are main producing areas of agricultural products in the Northeast Plain. In the “National Wetland Protection Project Planning,” the Sanjiang Plain has been listed as a key area for the protection and restoration of wetlands in China. Therefore, the contradiction
between agriculture and wetlands for water and land should be coordinated as the prerequisite to achieve the harmonious coexistence of natural wetlands and farmlands.

To solve this contradiction, researchers should develop a scientific agricultural production mode for sustainable development to balance the demand for food and environmental protection of wetlands. Agricultural developers must determine the balance point between the increase in arable land and the decrease in wetland area; the increase in rice-planting area and the increase in water shortage; and the grain yield and wetland conservation. In this method, we cannot only guarantee the demand of grain production but also effectively protect the wetland environment. This report aims to effectively assess the current agricultural production mode in the main grain-producing areas and determine the problems and contradictions in the existing agricultural production mode of the Amur River Basin. We also aim to analyze the main factors affecting the current mode on wetlands, promote step-by-step investigation and evaluation of the current agricultural production mode, assess the influence of agricultural modes on wetlands, and provide effective suggestions on environment-friendly green agriculture production. This report is of great significance to establish a long-term mechanism for sustainable agricultural development in the Amur River Basin in the future. The proposed mechanism could also promote the restoration of the ecological environment and the harmonious coexistence of man and the environment.

1.2 General situation of wetlands in the Amur River Basin in China

1.2.1 General situation of the Amur River Basin

The Amur River Basin (41° 45′ - 53° 33′ N, 115° 13′ - 135° 05′ E) is a broad area. It is the fifth largest basin in the world. The Mongolia Plateau is located on the west of this basin. Thirteen provinces of Mongolia, China, and Russia and a small part of North Korea (Fig. 5) all surround this basin.

![Fig. 5. Amur River Basin (Yang, 2013).](image)
The area of the Amur River Basin measures about $208 \times 10^4 \text{ km}^2$, in which $101 \times 10^4 \text{ km}^2$ belongs to China, and the other area belongs to Mongolia. The population distribution is extremely uneven in this basin. The total population is between $70 \times 10^6$ and $80 \times 10^6$. Among them, $5 \times 10^6$ of the population live in Russia, about $6575 \times 10^6$ or $75 \times 10^6$ of them live in China, and only less than $5 \times 10^4$ of them live in Mongolia (Yang, 2013). The Amur River Basin in China is mainly distributed in Heilongjiang, Inner Mongolia, and Jilin Province. The Changbai Mountains are located in the east, and the Small Hinggan Mountains are located in the north. The three columnar mountains siege semicircle shape, and the inner sides comprise the Sanjiang Plain and the Songnen Plain.

The east of the Amur River Basin mainly belongs to the temperate humid monsoon climate and is the most northern margin of the global monsoon climate. The west of the Amur River Basin is mainly influenced by continental climate. The average temperature ranges between -8°C and 6°C in the basin every year, and the spatial and temporal distributions are significant. The average temperature in January ranges from -20°C to -32°C, but under the influence of the sea of Okhotsk, the temperature in the eastern Pacific coast is 10°C higher than the normal value. The average temperature in July ranges from 17°C to 24°C in the entire basin, but the coastal temperature is lower than the inland temperature. The average annual precipitation is between 250 and 800 mm in the basin, and the spatial and temporal distributions are significant. More than 50% precipitation results in the hottest summer, and the precipitation in nearly 7 months of dry season (January to April) is only 25%. Precipitation is mainly concentrated in the coastal areas in space, gradually decreasing westward (Yang, 2013).

The trunk stream of the Amur River Basin system is the Heilongjiang River, and the main tributaries are the Songhua River, Ussuri River, and Nen River. Up to 12 families and 60 species of lichen plants, 67 families and 419 species of bryophytes, 23 families and 103 species of ferns, 117 families and 2038 species of seed plants, 2 families and 36 species of cyclostomatous animals, 19 families and 98 species of fish, 6 families and 13 species of amphibians, 4 families and 17 species of creeping animals, 382 species of birds, and 21 families and 104 species of mammals have been identified in this basin system (Tian et al., 2007; Cui, 2006).

1.2.2 General situation of wetland in the Amur River Basin

A large area of wetland exists in the Amur River Basin. The area of natural wetland is $600 \times 10^4 \text{ hm}^2$, which accounted for 6.63% of the land area of the Amur River Basin. Up to $200 \times 10^4 \text{ hm}^2$ of the constructed wetland (paddy field) area also exists in this basin, which accounted for 2.21% (Fig. 2). Large area of wetland exists in the Amur River Basin. The area of natural wetland is $600 \times 10^4 \text{ hm}^2$, which accounted for 6.63% of the land area of the Amur River Basin. Up to $200 \times 10^4 \text{ hm}^2$ of the constructed wetland (paddy field) area also exists in this basin, which accounted for 2.21% (Fig. 6).
The natural wetland is mainly distributed in the Great Hing’an Mountains, Small Hing’an Mountains, and the eastern mountains, including the Changbai Mountains, Sanjiang Plain, and Songnen Plain (Fig. 7).

Great Hing’an Mountains: All of the Hulun Buir Inner Mongolia League and the entire area of Inner Mongolia Great Hing’an Mountains forest industry group mainly include the Great Hing’an Mountains, Hulun Lake, Hui River area, Chuoer River Basin, and Wuergai marsh area. The area of wetland is $131.5 \times 10^4 \text{hm}^2$. 
Small Hing’an Mountains and the eastern mountains: The Small Hing’an Mountains in the east of Nen River – Bei’an – Harbin mainly include the Huma River, Xunbiela River, Wudalian River, Tangwang River, Xingkai Lake, Xiao Xingkai Lake, Jingbo Lake, and Lianhua Lake. The total area is $115.5 \times 10^4$ hm².

Changbai Mountains: The long railway to the east of Kuandian – Fushun line to the north, Wanda Mountains, Zhangguangcai Mountains, the southern Lao Ye Mountains, the hinterland of Changbai Mountain, the Yisha River, the Changbai Mountains nature reserve, Songhua Lake, lake nature reserve, reservoir, riverside, and river are included. The total area of wetland is 28.4 hm².

Sanjiang Plain: The low plain of the Heilongjiang River, Songhua River, and Ussuri River alluvial and the low plain of Muleng – Xingkai Lake and lacustrine plain low formation include the Sanjiang Plain in the north of Wanda Mountains and the Muleng – Xingkai Lake plain in the south of Wanda Mountains. This area also mainly includes the plain in Northeast Sanjiang, Hong River Nature Reserve, Qixing River, Naoli River Basin, and the lower reaches of the Dulu River. With a total area of 155.8 hm², the Sanjiang Plain is one of the most concentrated areas of wetland in China.

Songnen Plain: This area includes the Jilin – Tongyu – Qian'an – Yitong line to the north of the Songnen Plain. The Xianghai, Momoge, Zhalong, Horqin, Changjiang, Tumuji, and Longzhao swamp areas are also included. The area of the wetland is $169.7 \times 10^4$ hm² (Tan, 2004).

According to the remote sensing statistics of the Chinese Academy of Geological Sciences in 2012, under the dual effects of global climate change and human activities, the wetlands in the Amur River Basin are shrinking and the water area is decreasing. The reduction of wetland is mainly transformed into arable land, and its conversion rate increased from 7.11% in 1992–2000 to 15.64% in 2000–2010. The doubling of the conversion rate indicates that the main factors leading to the significant degradation of wetlands are agricultural reclamation, resulting in extraction of groundwater, degradation of the surrounding wetlands and the decrease of the water area (Donghua et al., 2012).

1.3 Classification and function of wetlands in the Amur River Basin

1.3.1 Classification of wetlands

In accordance with the “Convention on Wetlands,” on the basis of the definition of wetland and wetland classification system in the wetland directory, and combined with the specific status of wetland in the Amur River Basin, the wetland of the Amur River Basin is divided into four types: riverine wetlands, lacustrine wetlands, ponds, and marshy meadow.
wetlands (Tang, 2009). Each type of wetland area is shown in Fig. 3 (data from the Statistical Yearbook of the provinces).

![Fig. 8. Statistics of different wetland types in the Amur River Basin ($\times 10^4$ hm$^2$).](image)

The main trunk is the Heilongjiang River in the Amur River Basin, which comprises a large number of rivers and streams. The larger tributaries in the upstream are the Pangu River, Huma River, and Fabiela River. The main tributaries are the Songhua River, Ussuri River, and Lianhua River in the downstream. Many river wetlands (Guo, 2007) exist in the Amur River Basin, including several reservoir ponds and natural lakes. Large areas of wetlands are formed at the periphery of the lakes and reservoir ponds. Within the basin, a large area of plain exists, in which the area of the marsh meadow wetlands is the largest, measuring 398 hm$^2$.

1.3.2 Function of wetlands

Numerous wetland resources are available in the Amur River Basin. As an important ecosystem on earth, the function of the wetland ecosystem on earth is irreplaceable. This ecosystem forms the earth’s biosphere with a marine ecosystem and a forest ecosystem. Wetlands are extremely rich in biodiversity, with many rare birds, plants, and fish living around these areas (Dong, 1999; Huang et al., 2007; Yang et al., 2005). Wetlands comprise the living space for a large number of living beings. Such areas provide adequate food supplies and a large scope of activities to animals and plants. Moreover, wetlands provide food, water, and some raw materials for life.
Wetlands also play an important role in resisting flood, regulating runoff, controlling pollution, improving climate, and beautifying the environment (Tan, 2004). In addition, wetlands perform a strong cultural and economic function, as well as provide human resources and important economic resources of sideline products (Na et al., 2013). The specific functions of wetlands can be summarized in the following aspects:

Biodiversity and habitat of animals: Wetlands serve as a significant habitat for many species (Shi et al., 2012). Regardless of the type of wetland, the water flow in the wetland contains several nutrients, such as abundant nutrient salts and organic debris, which provide food and fertilizer for animals living around the wetlands. Therefore, many animals such as birds, fish, amphibians, and mammals exist in the surrounding wetlands. Such areas also offer a winter home for migrating birds. More than 300 species of birds can be found in the wetlands of China, and this number accounts for about one third of the total number of birds in the whole country. About half of the birds of China’s national first-level protection are living in wetlands.

Wetlands purify water body degradation pollution: Various microbes, planktons, and saprophagous animals are growing in wetlands. Microorganisms can degrade or transform the harmful elements of polluted water and pollutants in the wetland by decomposition, such as biological absorption and chemical synthesis in vivo. When polluted water flows through the wetland, the pollutants in the water body can be effectively degraded. In this way, the wetland has played a role in purifying the water body.

Fig. 9. Oriental stork (*Ciconia boyciana*) (*Photo by Mr. Mingjiang*)
Regulate the amount of water and local climate: Wetlands are natural storage pools. During a rainstorm and flood struck, wetlands can accumulate flood efficiently, reduce damage of flood peak, and thus play the efficacy of flood drainage. The water resources of accumulation in the wetland can be a good supply of downstream or the surrounding areas in the dry season. Wetlands contain adequate water, carrying a wide range of heat exchange and water exchange in the atmosphere. Consequently, wetlands play an important role in reducing the temperature difference between day and night, increasing the humidity in local areas, reducing the amount of dust in the atmosphere, and so on.

Social and economic functions: Wetlands demonstrate good social and economic efficiency and can provide abundant fishery resources and water resources for humans. Given the characteristics of wetlands, we can develop aquatic plant, waterfowl, fish, and livestock breeding, as well as provide comprehensive agricultural and sideline products for people. Additionally, wetlands exhibit a beautiful natural landscape. We can reasonably develop a wetland protection park, which will provide ornamental value and bring certain economic income for people, thus promoting good publicity for the protection of wetlands.
2. Existing agricultural production modes and their effects on wetlands

2.1 Agricultural production modes in the Amur River Basin

As an important part of the earth’s ecosystem, the wetland ecosystem exhibits functions and effects that cannot be replaced by other ecosystems. Given the large scale of agricultural activities, the large areas of natural wetland in the Amur River Basin shrink. The main reason for the influence of agricultural activities on wetlands is irrational agricultural production mode (Guo, 2007; Huang, 2005).

Agricultural development has experienced several stages of traditional agriculture, petroleum agriculture, and modern agriculture. Traditional agriculture is a type of manual labor mainly adopted by humans and animals through the use of hand tools made of iron and other metals, under the condition of natural economy. This type of agriculture is also a kind of farming methods and techniques accumulated by generations of agricultural production. The petroleum agriculture model is the general name of the highly industrialized agriculture based on cheap oil (Liu et al., 2009). Modern agriculture is a kind of agricultural production based on modern advanced agricultural science and technology, which adopts sustainable development and green ecological means. In the Amur River Basin, early productivity is regressive; to a large extent, the traditional agricultural farming mode is still used. Although the environmental damage of using traditional agricultural mode is very small, the production efficiency is extremely low and cannot meet the demand of the population brought by the population growth. To increase the grain production, the Amur River Basin gradually changed from traditional agriculture to petroleum agriculture and began to use much of agricultural machinery and chemical fertilizers. The grain output meets the people’s needs, but the environmental damage caused by petroleum agriculture is enormous (Zhang, 2001; Liu, 2014).

The main crops cultivated in are the Sanjiang Plain maize, soya bean and rice (Zhou & Liu, 2005). The annual mean temperature increased by 1.0-2.5°C in Northeast China since the
1980s (Yang et al., 2007). This results in a prolonged growing season and in a northward shift of the 1°C isotherm, allowing the northern expansion of paddy field rice cultivation (Wang et al., 2009). From 1982 to 2002, the crop cultivation area increased by 8.6 % in Northeast China because of the growing belts of rice and maize shifting 200–300 km Northward (Yang et al. 2007; Lenz-Wiedemann et al., 2012).

To date, agricultural development of the Amur River Basin has continued for more than 50 years. Although considerable progress has been made in grain production, in the high grain yield, the dominant position remains in the backward agricultural production mode. In the basin, the mode of traditional agriculture and the mode of petroleum agriculture coexist (Luan et al., 2013).

The extensive use of fertilizers and pesticides as well as the introduction of high-yield crops has increased the grain yield to a certain extent. Reliance and the extensive unscientific use of chemical fertilizers lead to the excess fertilizer release to the environment, causing surface runoff pollution and forming a wide range of surface source pollution. The use of a large amount of groundwater declines the groundwater level, and the wetlands dry up with the ground down (Liu et al., 2000). This phenomenon has caused irreversible pollution to the environment, and the destruction of the wetland ecosystem has become increasingly serious (Rao et al., 2011). Considering the reclamation and utilization to a large area of wetlands, the wetland area has been reduced, the sewage purification capacity has been reduced, coupled with agricultural non-point source pollution directly into the wetland; consequently, the water quality of wetlands has continuously deteriorated (Liu & Ma, 2002).

Fig. 10. Pesticides’ usage (Photo by Mr. Yuanchun Zou)
2.2 Influence and evaluation of agricultural water resource utilization on wetland hydrological regulation function

The general development of the wetland usually develops in the relatively flat terrain. Additionally, the soil bulk density is small, but the gap is large, which is the natural “sponge” of the water storage and flood control. According to statistics, about 96% of the world’s available freshwater is stored in wetlands, which act as huge “water storage pools.”

The water-storage capacity of wetlands is mainly related to the water-holding capacity of soil. The water-holding capacity of the marsh soil is twice to eight times higher than that of the general mineral soil. The saturated water content of the soil surface of peat soil and peat bog soil in the Sanjiang Plain was up to 6000 g/kg to 9000 g/kg, and the humus marsh soil and meadow marsh soil were 1000 g/kg to 6000 g/kg. From the surface to the bottom, the water-holding capacity of the soil decreased rapidly (Table 1). Given the Sanjiang Plain of China as an example, in the root and peat layers of the swamp and the swamp soil, the porosity ranges from 72% to 93%, the saturation of water-holding capacity is 830% to 1030%, and the maximum water-holding capacity is 400% to 600%. The water-storage capacity is about 8100 m$^3$/hm$^2$, and the water-storage capacity of marsh soil is up to 38.4 million m$^3$ in the whole area. Large areas of small lakes and wet meadow wetlands exist in the Song-Nen Basin. The weakening flood pulse plays an important role in weakening the flood pulse of Songhua River and Nen River, thereby reducing the peak. Given the Tao Er River and the wetlands of Huolin River as examples, during the flood in 1998, a total storage of flood in the wetlands of the two river basins reached 60 × 10$^8$ m$^3$, which is equal to a large reservoir (Liu, 2005). The microtopography is usually more complex in the plain marsh. For instance, many closed-disk depressions exist in the wetlands of the Sanjiang Plain. When the surface-water level rises to a certain height, the water in these depressions may establish a connection with waterpower. As such, the wetland exhibits an obvious dominant storage space, as well as a large hidden water-storage space (Lv, 2008).

Table 1 Water-holding capacity of swamp soil (Liu & Ma, 2002).

<table>
<thead>
<tr>
<th>TYPE</th>
<th>Depth (cm)</th>
<th>Saturation of water-holding capacity (g/kg)</th>
<th>Capillary water capacity (g/kg)</th>
<th>Field water-holding capacity (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meadow marsh soil</td>
<td>0—8</td>
<td>1240</td>
<td>1070</td>
<td>850</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>930</td>
<td>750</td>
<td>440</td>
</tr>
<tr>
<td>Mud swamp soil</td>
<td>0—10</td>
<td>1240</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10—20</td>
<td>690</td>
<td>490</td>
<td></td>
</tr>
<tr>
<td>Humus marsh soil</td>
<td>0—20</td>
<td>6100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20—30</td>
<td>5630</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Existing agricultural production modes and their effects on wetlands

<table>
<thead>
<tr>
<th>Peat bog soil</th>
<th>0—20</th>
<th>8600</th>
<th>6080</th>
<th>4720</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20—35</td>
<td>6120</td>
<td>5560</td>
<td>4480</td>
</tr>
<tr>
<td></td>
<td>&lt;35</td>
<td>600</td>
<td>330</td>
<td>310</td>
</tr>
<tr>
<td>Peat soil</td>
<td>0—15</td>
<td>9700</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18—37</td>
<td>8450</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40—55</td>
<td>6180</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56—62</td>
<td>6540</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After the natural marsh reclaimed, the physical structure related to the soil hydrological regulation has changed significantly. The soil bulk density and the proportion increased while the porosity reduced (Table 2). The capillary absorbed water content, saturated water content, field water capacity and maximum hygroscopicity were all decreased as the increased reclamation periods gradually (Table 3).

### Table 2. The bulk density, specific gravity and porosity of soil before and after marsh reclamation (Wang & Yang, 2001)

<table>
<thead>
<tr>
<th>Types</th>
<th>Depth (cm)</th>
<th>Bulk density (g/cm³)</th>
<th>Specific gravity</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural marsh</td>
<td>0—8</td>
<td>0.59</td>
<td>1.82</td>
<td>74.4</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>0.80</td>
<td>1.99</td>
<td>67.3</td>
</tr>
<tr>
<td>Marsh soil cultivated for 2 years</td>
<td>0—8</td>
<td>0.74</td>
<td>2.13</td>
<td>69.4</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>0.87</td>
<td>2.17</td>
<td>65.1</td>
</tr>
<tr>
<td>Marsh soil cultivated for 7 years</td>
<td>0—8</td>
<td>0.90</td>
<td>2.24</td>
<td>64.6</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>1.11</td>
<td>2.30</td>
<td>59.0</td>
</tr>
</tbody>
</table>

### Table 3. Change of physical properties of soil water after marsh reclamation (Wang & Yang, 2001)

<table>
<thead>
<tr>
<th>Types</th>
<th>Depth (cm)</th>
<th>Capillary absorbed water content (%)</th>
<th>Saturated water content (%)</th>
<th>Field water capacity (%)</th>
<th>Maximum hygroscopicity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural marsh</td>
<td>0—8</td>
<td>106.5</td>
<td>123.6</td>
<td>85.2</td>
<td>30.30</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>74.7</td>
<td>92.8</td>
<td>44.1</td>
<td>8.66</td>
</tr>
<tr>
<td>Marsh soil cultivated for 4 years</td>
<td>0—8</td>
<td>45.6</td>
<td>53.7</td>
<td>32.7</td>
<td>7.36</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>55.8</td>
<td>69.4</td>
<td>41.3</td>
<td>8.30</td>
</tr>
<tr>
<td>Marsh soil cultivated for 7 years</td>
<td>0—8</td>
<td>50.2</td>
<td>58.4</td>
<td>29.7</td>
<td>6.06</td>
</tr>
<tr>
<td></td>
<td>8—16</td>
<td>44.5</td>
<td>54.9</td>
<td>28.8</td>
<td>6.46</td>
</tr>
</tbody>
</table>
The water supply function of wetlands is mainly demonstrated in recharging groundwater and recharging river runoff. Wetlands often present a direct hydrographic relation to the regional groundwater aquifer, especially the relationship of mutual replenishment and infiltration, which often occur between shallow groundwater and wetland hydrology. Wetlands are located in different parts of the landscape. Thus, the effects on surface water and groundwater also vary. When the water level in a wetland is lower than that of the surrounding land surface, groundwater inflow will occur. If the water level in the wetland is higher than that of the surrounding water, the groundwater will flow out of the wetland. Seasonal water wetlands are more or less dependent on groundwater. Obvious mutual replenishment relationship exists between groundwater and surface water. In particular, the groundwater exerts an important backwater effect on wetland. The change in groundwater level also significantly affects the wetland ecosystem.

The routes of marsh recharge groundwater are both direct and indirect. In the direct route, water directly penetrates into the aquifer through the swamp soil. In the indirect route, water moves horizontally first into the permeable soil or river through the soil, and then groundwater is recharged through the river. The wetland and groundwater demonstrates the relation of mutual replenishment and infiltration on the quantity of water. The hydraulic relationship between surface water and groundwater chemical characteristics is also very close in wetland. In Zhalong wetland, shallow groundwater exhibits two typical circulation patterns influenced by surface water of wetland. Nitrogen and phosphorus in groundwater are mainly derived from the input of surface water rather than the vertical leaching of the soil. The water in wetland lakes and rivers is $\text{HCO}_3^-$ - Na type water of medium mineralization, and the groundwater type is changed from $\text{HCO}_3^-$ - Ca·Na·Mg to $\text{HCO}_3^-$ - Na·Ca (Wang & Zhang, 2007).

The function of wetland water supply is affected by many factors, such as wetland soil moisture, permeability, and porosity. Furthermore, the changes in wetland utilization mode, evaporation intensity, and hydrological regime indirectly affect the water supply function of wetland. The development process of the wetland will often reduce the local underground water level. If the wetland is damaged or has disappeared, it is impossible to supply water for the underground aquifer, and groundwater resources will be reduced.

Since the 1980s, a large area of marsh land in the Sanjiang Plain was reclaimed as farmland, which reduced the amount of water supply from marsh to the groundwater but increased the amount of groundwater exploitation. This event led to a continuous decline in groundwater levels, in which regional groundwater level generally decreased by 3 m to 4 m; in some rice-planting areas, the water level dropped by 10 m (Yin et al., 2003). In 1999, the groundwater level of advance, farm 850, and other farms decreased by 2.61, 0.94, and 0.11 m respectively, compared with that in 1997. Moreover, the corresponding paddy area increased by 39% to 127% (Liu & Ma, 2002). Although the entire groundwater level decreased, the site-specific differences could be observed according to the distance from rivers (Wang, 2015). The groundwater
decreased rate in the near river area (< 5.5 km) was 0.27 m/a during 2008–2012, while that in the far-off river area (> 5.5 km) was 0.56 m/a, especially for the irrigation area of 0.80 m/a, because of the recharge is inadequate.

![Groundwater pumped for irrigation of paddy fields](image)

**Fig. 11.** Groundwater pumped for irrigation of paddy fields (Photo by Mr. Yuanchun Zou)

The functions of wetlands to regulate runoff and flood are closely related to the structural characteristics of soil and vegetation of the wetland. Wetland soil presents special hydrological and physical properties; thus, flood is stored in the soil or in the form of surface water in lakes and swamps, thereby directly reducing the amount of flooding downstream. A part of the flood can be discharged from the stored water in a few days, weeks, or months. Another part can be discharged through evaporation and infiltration into underground water in the flowing process. In addition, the wetland vegetation can increase the surface roughness, which can reduce the flood velocity. This phenomenon avoided all floods to reach the downstream simultaneously, reduced the water level of downstream flood, and released the water stably and slowly, which can disperse and eliminate the huge energy brought by the flood effectively. The two processes reduced the water level of downstream flood peak and prolonged the time of flooding in the land (Fig. 12).
Large areas of marshes exist between the Baoqing hydrologic station of the upper reaches and Caizuizi station of the middle reaches of the Naoli River Basin in the Sanjiang Plain. The wetland rate reaches 32.7%. When the river floods, and the massive floods diffuse in the storage in the flood plain swamp, the water-retention effect of marsh decreases the amount of flood peak of the Caizuizi station in summer by 50% (relative flow), thus postponing the flood season (Liu, 2007).

The original area of wetland in the Sanjiang Plain measured 34000 km². With decades of large-scale development in the Great Northern Wilderness, 34 state farms have been set up in Sanjiang. All the wetlands are embedded in the arable land of the large modern farm group. Since the 1990s, with rice waterlogging control, large-scale developments of paddy fields, strong row of heavy irrigation, and other water conservancy facilities have been instinctively launched, and
the surface water drainage and groundwater levels declined very seriously. More than $100 \times 10^8$ m$^3$ of surface water stored in wetlands decreased by $87 \times 10^8$ m$^3$ (Jiang, 2004). More than 200 wetlands in the river of the Sanjiang Plain appeared atrophic and dry, and more than 4,000 ponds shrank or disappeared. The unique system of mutual cycle and transformation of wetland water, surface water, and groundwater is broken. According to the results of the remote sensing image analysis by Song et al. (2014), the wetland area in the Sanjiang Plain decreased by 38% from 1976 to 1986 and by 16% in 1995; by 2005, the area further decreased by 31%. The area from wetland to agricultural land accounted for 91% of the loss of wetlands, whereas the conversion of grasslands and forests accounted for only 7% of the loss of wetlands. The adjustment of the agricultural activities was directly or indirectly affected by the policy system and market policy.

Because of the large-scale land conversion from dryland to paddy field, the soil water content of dry land is declining, while that of paddy field is increasing year by year. As the ecosystem type with the highest soil water content per unit area, the average annual soil water content of wetland was only $4.4 \times 10^8$ m$^3$, which was mainly due to the fact that large-scale agricultural reclamation resulted in the decrement of wetlands area in this area. Wetland preserves 8.4% of the total soil water within the whole Sanjiang Plain, despite its distribution area is only 4.97%.

Fig. 14. Soil water content variations in Sanjiang Plain (2000–2015)

Wetlands, which comprise a huge reservoir, play a strong function in maintaining water balance and ecological balance. The wetland in the Sanjiang Plain is the natural precious trace created by heaven, which cannot be replaced. Thus, we should establish some measures, such as building ditches and dams, returning farmland to forest and grassland, building protection zone, moving village farm, and improving farm water conservancy system to ensure the wetland ecological water use, restore and rebuild the marshes, cherish, protect, and rationally exploit and use the resources in Sanjiang Plain.
2.3 Influence and evaluation of ditch on wetland

Water is the most important influence factor of wetlands. The amount of water will directly affect the dynamic balance of the wetland ecosystem and its normal function. Water shortage is the key factor to the degradation of wetland (Lv, 2004). Thus, the effect of water on the wetland is very important because it directly affects the biological distribution of wetlands, determines the regional species and communities, and restricts the types and the distribution of wetlands.

In the existing mode of agricultural production, an important agricultural means is to build the ditch and change the dry land into paddy field. People dig ditches to drainage and open channels to build up fields in a large area relying on rivers and natural wetlands. Ditch is a pure man-made product with two kinds of functions, namely, water supply and drainage. The emergence of ditch has completely changed the natural hydrological pattern; thus, the water input and output of wetlands and natural water retention time all changed in many aspects. Consequently, the ditch plays an important role in the development and evolution of the wetland ecosystem.

Fig. 15. The main ditch with broad and straight morphology different from natural marsh rivers (Photo by Mr. Yuanchun Zou)

Given the Sanjiang Plain as an example, according to the Statistical Yearbook of Heilongjiang, the length of 116 km of the main river has been excavated in 1986; 76 branch rivers were excavated with total row trunks measuring more than 700 km long. The built branch ditches, lateral ditches, and small ditches were more than 1600, measuring more than 4,000 km long. Various bridges, culverts, gates, strong row of stations, and total 820, two flood control dykes, total earthwork volume is more than $6200 \times 10^4 \text{m}^3$. In 1991, the area of $293.65 \times 10^4 \text{Mu}$
in the Sanjiang Plain has been changed from dry land into paddy field. The irrigation area increased to $293.95 \times 10^4$ Mu, and the drainage area was $1003.97 \times 10^4$ Mu. Up to 23 small reservoir bridges were built, 215 irrigation and drainage stations were established, and 18407 electromechanical wells were developed.

From the data and the observation of the wetland, we can analyze that natural wetlands have been divided by artificial rice fields. Natural wetlands scattered around the paddy fields, and the paddy fields are connected by a large number of ditches and ditches. The ditches increased the flow of water in the wetland. Under the natural environment, the water flow rate is very slow and thus can play a very good role in water conservation. After connecting with the ditch, the water body of the river is rapidly discharged into the runoff along the ditch; hence, the water of the wetland cannot be guaranteed, and wetlands will present water shortage and even dryness because of ditch drainage (Xi and Lv, 2007). According to the latest water conservancy atlas of reclamation area in Heilongjiang, ArcGIS is employed for digital processing of ditches in the Sanjiang Plain. The existing Sanjiang Plain ditch map is shown in Fig.16.

![Fig.16. Channel distribution map of Sanjiang Plain.](image)

As clearly shown in Fig. 16, the channel network is very dense and has formed a huge scale. Most of the wetlands and ditches overlap, and the wetlands embedded in the ditch network. The constructed wetland has significantly changed the characteristics of natural wetlands. The natural wetlands and constructed wetlands jointly form a new wetland system. These wetlands do not only
broke the original landscape pattern in the area but also changed the natural hydrological link among wetlands and formed a new hydrological pattern. Under the control of the hydrological pattern, the amount of water stored in the wetland decreases, and the ecosystem is in a state of extreme instability. The wetlands are gradually degraded, thereby declining the regional environmental quality. This event has seriously threatened the survival of wetland species and even the existence of wetlands, which simultaneously increased the degree of wetland landscape fragmentation, hindering the sustainable development of regional resources and the environment (Tong, 2012). In recent decades, the agricultural development activities have led to the great changes of wetland water level in the small Sanjiang Plain. Moreover, the construction of irrigation canal system and flood dike interfered with the dynamic change of flood plain, and the increasingly reduced area of flood plain led to the increase of the peak flow and runoff, causing the loss and fragmentation of wetland, which significantly influenced the wetland community and biodiversity (Liu et al., 2004; Chen et al., 2014).

Acres of channel networks come into a state of manual control to a large extent and scale, which evolved into the artificial collateral circulation system within the natural hydrologic cycle system (Wang et al., 2005). The channel density is an important index used to measure the accessibility of a river basin. In terms of watershed wetland, a greater density promotes greater accessibility (Tong, 2012). The total length of ditches in the Sanjiang Plain area was 24368.4 km, which was calculated using the total plain area of $10.88 \times 10^4 \text{km}^2$, and the index of ditches was 0.22 km/km$^2$. By calculating the area of low relief, that is, $7.78 \times 10^4 \text{km}^2$, the index of ditches will be 0.31 km/km$^2$. As shown in Fig. 1 and Fig. 2, the distribution of ditches significantly differed among counties in the Sanjiang Plain. Among these counties, the length of the channel in Hulin City is 3404.5 km, which is the largest, followed by Tongjiang City with channel length of 2880.3km. The third is Baoqing County with channel length of 2872.5km. However, the largest county in the channel index is Youyi County, with index of 0.75 km/km$^2$. The second is the Tongjiang City, with index of 0.47km/km$^2$, and the third is Hulin City, with index of 0.37km/km$^2$.

By analyzing the available statistical data of 23 administrative units in the Sanjiang Plain, a positive correlation is observed between the length of the ditch and the loss area of wetland ($r=0.929$, $p<0.001$). The positive correlation between the density of ditches and the loss area is also significant ($r=0.655$, $p=0.001$). According to the linear regression, the channel length can explain 86% of the loss of the wetland area. From the linear regression equation, we can observe that the length of the ditches increased by 1 km, and the wetland will lose an area of 0.01 km$^2$ (Fig. 17).
In addition to the effect on the distribution and area of wetlands, the ditch will affect the material balance of residual wetland. The deposition flux of the ditch system was significantly higher than that of the natural wetland, in which significant differences existed in the composition of the sediment. In the former, the sediment occupies an absolute advantage, and the latter mainly litter. Changes in circulation also cause some physical and chemical changes in the elements. No significant difference existed in the total iron content in the ditches at all levels and natural wetland sediments, but the iron oxide and its composition have changed, leading to the loss of some elements, such as the contents of nitrogen, phosphorus, and other elements (Su et al., 2015). Other studies have indicated that the construction of drainage ditches changed the release process and migration pathways of soluble organic carbon (DOC) in wetland soils (Xi, 2007).
2.4 Impact and evaluation of irrational development on wetland area

The Chinese population comprises 1/6 of the world population. A population this huge comes with an enormous food demand. Therefore, aggressive agricultural reclamation in the Amur River Basin has been initiated during the development of the PRC. In the Sanjiang Plain of the Amur River Basin, before the large-scale land reclamation, the area of reclamation was 82 × 10^4 hm² and the reclamation accounts for approximately 7.53% of the total Sanjiang Plain. Because the land reclamation area is small, the locale is still relatively primitive, and large areas of wetlands are still visible (Tan, 2004). With the establishment of a new China, the population continues to grow, the economy progresses, and the demand for food has grown exponentially. During the end of the 1950s, the Sanjiang Plain entered a period of rapid development. Concurrently, other areas of the Amur River Basin that have also massively developed, such as the Zhالong and Songhua River watershed wetlands, have suffered great damage (Na et al., 2015).

From the 1950s to the present, the Sanjiang Plain of the Amur River Basin has experienced four development climaxes. First, from 1949 to 1960, during 12 years, 72.7 × 10^4 hm² cultivated lands were reclaimed, and the land reclamation rate increased to 13.9%. However, at that time, the new China had been founded, and the mechanization degree and development speed were slow; therefore, the impact on wetlands was not particularly pronounced. Second, from the beginning of the 1960s to 1977, in nearly 20 years, the cultivated land area had rapidly grown from 72.7 × 10^4 hm² to 212 × 10^4 hm², and reclamation rate reached 19.5%. In the middle of the 1970s, the Sanjiang Plain still remained relatively primitive. Third, during 1978 to 1985, the land area had rapidly increased to 297.3 × 10^4 hm² and land reclamation rate reached 27.3% because of further improvement in agricultural mechanization. The cultivated land area reached 311 × 10^4 hm² in 1980, and marsh and swampy meadow wetland areas decreased to 220 × 10^4 hm². Fourth, from mid-1980s to the present, the area of the newly reclaimed farmland reached 173.3 × 10^4 hm², the area of cultivated land in the entire area reached 473.3 × 10^4 hm², and land reclamation rate increased to 43.7% (Zhao et al., 2008; Song et al., 2008; Zhou et al., 2005). In the past 50 years, with the large-scale development of the Great Northern Wilderness, 52 state farms were built on the Sanjiang Plain, resulting in embedded wetland in a large modern farm and forms the landscape of wetland patches (Shi et al., 2010).

The area variation in the Qixinghe wetland in Sanjiang Plain from 1954 to the present represents a microcosm of the area variation. The wetland area has been invaded by large-scale farmlands, large population expansion, and the need for more residence, thereby sharply decreasing the area of Qixinghe wetland. The area of Qixinghe wetland was 3.6159 × 10^4 hm² in 1957 and decreased to 2 × 10^4 hm² in 2000 (Yu, Liu et al., 2014). The Sanjiang Plain wetland area shrunk by approximately 73.6% from 1950 to 2000 because of agricultural development.
The rapid conversion of natural wetlands and forests to agricultural lands caused by large-scale land reclamation not only decreases the wetland area and induces natural wetland and habitat loss but also affects many species of plants and animals that depend on wetlands to survive (Liu et al., 2004).

Changes in the cultivated land area in Sanjiang Plain were drawn according to the Statistical Yearbook, land resource surveys, and other related data of Heilongjiang Province (Fig. 19).

The Sanjiang Plain has developed in recent years, and the area of cultivated land has continuously increased since the founding of PRC. After 1975, the growth rate has been more prominent. The rapid growth rate of arable land is a clear response to the rapid reduction of wetland area. In the 1990s, the Heilongjiang government adopted policies to excessively pursue the grain output and build another Great Northern Wilderness, resulting in further reduction of wetlands in the Sanjiang Plain. The area decreased from $199.7 \times 10^4 \text{hm}^2$ in the 1980s to $155.8 \times 10^4 \text{hm}^2$ in 1998 (Wang et al., 2009).

Since 2000, Heilongjiang Province has increased the use of large machineries. In 10 years, large tractors have increased to nearly 800,000 units. The agricultural model changed from hands to using large-scale machineries; although the speed of farmland development was accelerated, the area of the wetland decreased exponentially. Specific data are shown in Table 4.
<table>
<thead>
<tr>
<th>YEAR (Unit)</th>
<th>Total power of agricultural machinery (000 kw)</th>
<th>Large and medium-sized farm tractor (Platform)</th>
<th>Small tractor (Platform)</th>
<th>Large and medium tractor farm implements (Platform)</th>
<th>Small tractor farm implements (Platform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1613.8</td>
<td>75553</td>
<td>65.2</td>
<td>19.2</td>
<td>62.8</td>
</tr>
<tr>
<td>2001</td>
<td>1648.3</td>
<td>78177</td>
<td>65.3</td>
<td>18.9</td>
<td>64.6</td>
</tr>
<tr>
<td>2002</td>
<td>1741.8</td>
<td>88266</td>
<td>68.0</td>
<td>19.4</td>
<td>69.4</td>
</tr>
<tr>
<td>2003</td>
<td>1807.7</td>
<td>99462</td>
<td>69.5</td>
<td>20.1</td>
<td>76.3</td>
</tr>
<tr>
<td>2004</td>
<td>1952.2</td>
<td>127795</td>
<td>71.6</td>
<td>22.2</td>
<td>83.6</td>
</tr>
<tr>
<td>2005</td>
<td>2234.0</td>
<td>217275</td>
<td>74.4</td>
<td>31.9</td>
<td>87.7</td>
</tr>
<tr>
<td>2006</td>
<td>2570.6</td>
<td>323087</td>
<td>75.5</td>
<td>40.9</td>
<td>104.5</td>
</tr>
<tr>
<td>2007</td>
<td>2785.3</td>
<td>381813</td>
<td>75.7</td>
<td>47.2</td>
<td>110.3</td>
</tr>
<tr>
<td>2008</td>
<td>3018.4</td>
<td>491795</td>
<td>71.4</td>
<td>59.3</td>
<td>113.2</td>
</tr>
<tr>
<td>2009</td>
<td>3401.3</td>
<td>583015</td>
<td>71.1</td>
<td>67.4</td>
<td>117</td>
</tr>
<tr>
<td>2010</td>
<td>3736.3</td>
<td>654789</td>
<td>9.3</td>
<td>75.9</td>
<td>118.1</td>
</tr>
<tr>
<td>2011</td>
<td>4097.8</td>
<td>732577</td>
<td>68.8</td>
<td>92.7</td>
<td>120.2</td>
</tr>
<tr>
<td>2012</td>
<td>4549.3</td>
<td>808875</td>
<td>66.5</td>
<td>104.5</td>
<td>119.6</td>
</tr>
<tr>
<td>2013</td>
<td>4848.7</td>
<td>873322</td>
<td>64.5</td>
<td>118</td>
<td>118.5</td>
</tr>
</tbody>
</table>

Table 4  Amount of main agricultural machinery (Heilongjiang Province Yearbook).

Fig. 20. **Tractor used for plowing paddy field** (Photo by Mr. Yuanchun Zou)
Songhua River is an important tributary of the Amur River Basin. The surrounding wetland is an important part of the Amur River Basin. As such, large-scale development of the river basin has severely damaged the wetlands of the Songhua River Basin. The wetland area has shrunk, whereas the construction land area has expanded; moreover, the forest land retention rate remains relatively high. In particular, the transformation of wetland—cultivated land and cultivated land—construction land is severe (Cao, 2014). Table 5 shows the changes in land use types in the Songhua River Basin from 2000 to 2010.

Table 5 Changes in land use types in the Songhua River Basin (Cao et al., 2014).

<table>
<thead>
<tr>
<th>BASIN</th>
<th>First-level land use types</th>
<th>In 2000</th>
<th>In 2005</th>
<th>In 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole basin</td>
<td>Cultivated land</td>
<td>23.56</td>
<td>23.63</td>
<td>23.79</td>
</tr>
<tr>
<td></td>
<td>Woodland</td>
<td>22.94</td>
<td>22.92</td>
<td>22.86</td>
</tr>
<tr>
<td></td>
<td>Wetland</td>
<td>4.22</td>
<td>4.09</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>Grassland</td>
<td>2.80</td>
<td>2.80</td>
<td>2.77</td>
</tr>
<tr>
<td></td>
<td>Constructional</td>
<td>1.46</td>
<td>1.52</td>
<td>1.60</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.63</td>
<td>0.64</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Wetland habitat fragmentation results in habitat loss, habitat area reduction, or habitat isolation; directly or indirectly changes the composition of species; and reduces the diversity of species and the loss of wetland ecosystem function (Shi, 2010).

In 2000, Wu YJ, Zhang SW, and other researchers reported that dry land distributed contiguously and the fragmentation index decreased by 96.43% compared with those in 1954. The area of the swamps decreased daily, and the fragmentation degree increased. In the past 50 years, large-scale agricultural development in the Wusuli River Basin in forest land and wetland has reduced, the degree of fragmentation has increased, and the effects of soil and water loss in Ussuri River has been enhanced (Wu et al., 2006).

The importance of wetlands to the ecology has been gradually realized, and many wetland protected areas have been established; in these areas, individual illegal reclamation of wetlands are prohibited were. However, few farmers privately reclaim wetlands; this practice is attributed to the low cultural level of some farmers, who are unaware of the existence of the law and the importance of wetland conservation and only focus on attaining huge profits. These factors induce the annexation of the wetlands by the surrounding farmlands from the wetlands’ edge to the center, contributing to reduction in wetland areas yearly.
The utilization rate of the developed land is insufficient. Reasonable use of scientific modes of agricultural production could further improve the per mu yield of the reclaimed farmland. The existing farmland utilization rate in most areas is approximately 75%. Without full utilization of the land and blindly reclaiming new lands, farmland resources will be wasted. The existing farmland use is unreasonable, and blind cultivation could lead to competition between the farmland and wetland for the land.

2.5 Impact and evaluation of inherent mode of agricultural production on the water environment of wetlands

Human land use activity is an important factor that influences the water quality of the natural bodies of water (Roberts et al., 2006). Point source pollution caused by urban and industrial waste waters has improved because the government has strengthened the awareness and management of the land in recent years. For agricultural lands, controlling water pollution is difficult particularly for pollution caused by non-point source sources from chemical fertilizers and pesticides used in agricultural production (He et al., 1998). Management of regional water environments should mainly focus on controlling agricultural non-point source pollution (Baker et al., 2003). Moreover, factors causing severe agricultural non-point source pollution comprise the unreasonable mode of agricultural production.

In agricultural production, human activities and excessive use of fertilizer causes severe surface water pollution in the Amur River Basin (Tian, 2006; Yan, 2008; NIU et al., 2013). Table 6 shows the monitoring data, including pollution parameters and index, in Jiaoyin County in 2001 – 2005.

Table 6 Major pollution indicator statistics of the Heilongjiang River (Jiaoyin section) (Tian, 2006).

<table>
<thead>
<tr>
<th>TERMS</th>
<th>Dissolved oxygen DO</th>
<th>Ammonia nitrogen NH₃-N</th>
<th>Nitrite nitrogen NO₂-N</th>
<th>Cyanide</th>
<th>Six valence chromiumCr⁶⁺</th>
<th>Cadmium Cd</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ci₀ (pollution parameter)</td>
<td>3.0</td>
<td>1.5</td>
<td>1.0</td>
<td>0.2</td>
<td>0.2</td>
<td>0.005</td>
</tr>
<tr>
<td>Pi (pollution index)</td>
<td>2.787</td>
<td>17.71</td>
<td>0.014</td>
<td>0.01</td>
<td>0.01</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The main pollutants in the region are organic pesticides, cyanide, sulfide, mercury, and chromium. The main sources of these are chemical fertilizers and pesticides used in agricultural production.
The main pollutants in the region are organic pesticides, cyanide, sulfide, mercury, and chromium. The main sources of these are chemical fertilizers and pesticides used in agricultural production.

The use of fertilizer, especially the input of nitrogenous fertilizers, induces loss of nitrogen and pollution of surface water. The utilization rate of nitrogen fertilizer is low; that is, only 30% – 50% of the nitrogen fertilizer applied is absorbed and utilized by the crops, and the remaining portion is lost during volatilization, denitrification, and leaching. After applying nitrogen fertilizer to the soil, the fertilizer enters the surface water and is lost to the environment through leaching, surface runoff erosion, and water loss (Dong et al., 2009). In 2005, economic losses caused by water pollution from agricultural production in Heilongjiang reached $62.76 \times 10^8$ RMB (Yan, 2008). The cost of water pollution in the agricultural sector is enormous. Hence, the existing agricultural model must be altered to reduce the amount of fertilizers and pesticides used and eventually minimize water pollution caused by agriculture.

![Fig. 21. Farmland drainage water pollution (Photo by Mr. Yuanchun Zou)](image)

Farmlands cannot be irrigated because the surface water is polluted. Under the existing agricultural model, irrigation uses large amounts of underground water, thereby reducing the groundwater level. Statistically, the total annual amount of groundwater that can be extracted is $30.14 \times 10^8$ m³, and the current annual production volume has reached $31.62 \times 10^8$ m³ in the Sanjiang Plain of the Heilongjiang reclamation area. Severe overexploitation of groundwater has decreased the groundwater level yearly in this area.
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The amount of water consumed during agricultural production has increased because of the large area of the farmland in the paddy field; this condition has worsened the groundwater exploitation. We obtained the statistics regarding agricultural irrigation and drainage machinery from Statistical Yearbooks of Heilongjiang (Fig. 22).

Fig. 22. Agricultural irrigation power machinery statistics (Statistical Yearbooks of Heilongjiang Province).

In Fig. 22, the box and circle lines represent diesel engines and electric motors used in agricultural irrigation, respectively. The number of agricultural irrigation and drainage machinery gradually increased from 2000 to 2013, indicating the increase in groundwater extraction from one aspect. The rice planting area increased from $2100000$ hm$^2$ to $4000000$ hm$^2$ in Heilongjiang Province from 1980 to 2013. The proportions of rice produced to the total grain output were drawn according to the Statistical Yearbooks of Heilongjiang Province (Fig. 23).
In Fig. 23, the dark gray histogram represents the percentage of the total grain yield of rice. The proportion of rice planting area has evidently increased yearly. In the past 20 years, especially from 2005 to 2013, the rice growing area in Heilongjiang Province has increased exponentially by about 20 times that of the planting area.

The paddy field area in the entire Sanjiang Plain increased from $9.2 \times 10^4$ hm$^2$ in 1983 to more than $53 \times 10^4$ hm$^2$ in 1996; the area could potentially increase further. In the Honghe farm, which has $104$ hm$^2$ of arable land, the rice planting area was only $72$ hm$^2$ in 1992 but expanded to $11.12 \times 10^4$ hm$^2$ in 1996, accounting for $60.2\%$ of the arable land area. The rice planting area of the Qianjin farm increased from $100$ hm$^2$ in 1996 to $1.03 \times 10^4$ hm$^2$ in 1991, increasing by 100 times ("Water Resources in Northeast China" Project Group, CAE, 2006).

Changing dry lands into paddy fields bring very high value. However, surface water cannot be effectively used, and electromechanical wells are used to extract groundwater; as such, most water used in the rice field is derived from drainage channels after irrigation with ground water. In this technique, only a very small amount of water infiltrates the ground, resulting in wastage of groundwater resources and serious damage to the stable structure of groundwater. This phenomenon leads to drying of a large area of the wetland (Ning et al., 2004). Unreasonable transformation of dry land into paddy field can reduce wetland water storage and cause drying of the wetland because of lack of water. Annual transit water volumes of Heilongjiang, Songhua, and Ussuri Rivers reached $2785 \times 10^8$ m$^3$ but are not reasonably used (Kang et al., 2003). Groundwater quality is also affected by varying degrees of pollution, such as in Songhua River; moreover, shallow groundwater is affected by pollution. Classes V and IV of water areas account for 15% of the total water area in the Sanjiang Plain, and classes IV and V of the water account
for approximately 28% of the total water area in the Songnen Plain (Chinese Academy of engineering, “Northeast Water Resources” project group, 2006).

Fig. 24. Conversion from dryland to paddy field (Photo by Mr. Yuanchun Zou)

Dam construction is another factor that affects the decline in wetland areas. Large and small dams and ditches have been established in the Amur River Basin. Until 1980, 19 reservoirs, 119 medium-sized reservoirs, 1734 small reservoirs, and 8 power stations were built around the basin (Kang et al., 2003). Water flowing through the wetlands is blocked, resulting in lack of water and eventually degradation. The establishments of water conservancy projects cut off the link between natural rivers and wetlands. Water is drained from ditches, thereby shrinking wetlands until they disappeared (Zhou et al., 2009; Zhang, 2007).

2.6 Impact and evaluation of the inherent mode of agricultural production on soil environment

The state of agriculture in China adheres to “harmony between man and nature,” which emphasizes the relationship of human to nature affinity, symbiosis, and integration (Hu, 2002). Rational coordination and efficient use of land can be achieved using reasonable crop species composition layout, crop intercropping, crop rotation, and other measures of rational close planting to integrated coordination (Peng, 1990). Crop rotation results in soil rotation, thus optimizing the ecological relationship among different crops as well as between the crop and the soil (Hu, 2002). However, these processes have not been extended because of the large-scale development in the Amur River Basin.
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Nourishing land means maintaining the vitality of the land and enabling its sustainable use (Xu, 2009) to prevent fertility decrease, soil salinization and desertification, and soil and water loss because of over-farming. The cultivation rate of black soil and chernozem has reached 74% and 72%, respectively, in Heilongjiang Province. Less investment, extensive cultivation, and extensive management has greatly reduced soil fertility. Input is equal to the output of arable land, accounting for only 14.8% of the arable lands keep balance between the input and output, while 75.2% of the lands obtain less output than the input. The fertility of the soil decreased by 1/3 after 20 years and by 50% after 40 years of using black soil. The deterioration of soil physical properties is aggravated by poor soil quality, leading to soil compaction, changes in soil properties, decrease in soil water content (Zheng, 2010), and increase in low-yield land area (Yi, 2014).

After China's Reform and Opening-up, the Chinese population has grown exponentially, thereby considerably increasing the food demand. In the early days of PRC, people pursued grain output excessively and neglected environmental protection because of the low level of agricultural science and the urgent need for food. Moreover, a large number of agricultural production practices violating the laws of nature have been implemented. Land is used without the balancing consumption and nourishment. Furthermore, large amounts of fertilizers are used when the quality of the soil declines. Single crop species are increasingly used, and crop rotation is not practiced. The land in the Amur River Basin has been polluted and destroyed to a great extent, resulting in serious ecological problems, such as land desertification, soil salinization, soil structure fertility change, and soil water content reduction (Zhao et al., 2006).

<table>
<thead>
<tr>
<th>SAMPLING SITE</th>
<th>Level</th>
<th>Organic matter (g/kg)</th>
<th>Total nitrogen (mg/kg)</th>
<th>Total phosphorus (mg/kg)</th>
<th>Total potassium (mg/kg)</th>
<th>Available nitrogen (mg/kg)</th>
<th>Available phosphorus (mg/kg)</th>
<th>Available potassium (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 team of 290 farm</td>
<td>0-20</td>
<td>59.50</td>
<td>2.00</td>
<td>1.40</td>
<td>29.40</td>
<td>440.90</td>
<td>191.00</td>
<td>262.00</td>
</tr>
<tr>
<td></td>
<td>20-40</td>
<td>4.60</td>
<td>0.40</td>
<td>0.60</td>
<td>30.90</td>
<td>249.40</td>
<td>65.70</td>
<td>68.00</td>
</tr>
<tr>
<td></td>
<td>After 30 years</td>
<td>6.41</td>
<td>0.42</td>
<td>0.20</td>
<td>2.67</td>
<td>54.6</td>
<td>22.69</td>
<td>57.17</td>
</tr>
</tbody>
</table>

- 077 -
### Table 7 Changes in soil fertility (Liu et al., 2000).

In Table 7, the contents of N, P, K in the two farms in Heilongjiang Province decreased after 30 years of reclamation, which could be attributed to the continuous intensive use without organic matter return since the founding of the PRC.

Application of chemical fertilizers and pesticides has become an important method for improving land output. This “modernization” of agricultural production is an important source of non-point source pollution (Tao et al., 2010). Table 7 shows the use of pesticides in Heilongjiang Province between 2001 and 2007 and the trend of pesticide use in Heilongjiang Province between 1997 and 2005 (Ma, 2009).

<table>
<thead>
<tr>
<th>Year</th>
<th>Use of pesticide (104t)</th>
<th>Year</th>
<th>Use of pesticide (104t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>3.10</td>
<td>2005</td>
<td>4.75</td>
</tr>
<tr>
<td>2002</td>
<td>3.54</td>
<td>2006</td>
<td>5.20</td>
</tr>
<tr>
<td>2003</td>
<td>3.66</td>
<td>2007</td>
<td>5.79</td>
</tr>
<tr>
<td>2004</td>
<td>4.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8 Use of pesticides in Heilongjiang Province in 2001–2007 (Ma, 2009).
Table 9 Change tendency of pesticide use in Heilongjiang Province during 1997–2005 (kg/hm\(^2\)) (Ma, 2009).

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.98</td>
<td>3.06</td>
<td>3.06</td>
<td>3.16</td>
<td>3.10</td>
<td>3.59</td>
<td>3.73</td>
<td>4.77</td>
<td>4.71</td>
</tr>
</tbody>
</table>

In Table 9, the level of pesticide use in Heilongjiang Province has increased yearly, and the usage is still gradually increasing. According to the Statistical Yearbook of Heilongjiang Province, the total use of chemical fertilizers was 5.78 × 104 t until 2013, which is equal to the use in 2007. This finding shows that green organic agriculture development has been successfully implemented, although several challenges persist.

Songhua River is an important tributary of the Amur River Basin. Massive fertilizer use in the Songhua River basin surrounding the farmlands has caused severe non-point source pollution of the basin. The stock of agricultural chemical fertilizer in the Songhua River Basin is 161 × 104 t, and pesticide use is 5.6 × 104 t (Li, 2012). Moreover, contaminated water flowing through the river has aggravated the degree of pollution in the Heilongjiang River.

In agricultural production, the irrational use of chemical fertilizers promotes the entry of nutrients such as nitrogen, phosphorus, pesticide residues, and other organic or inorganic pollutants to the bodies of water through surface runoff and farmland leakage, resulting in severe environmental pollution (Meng et al., 2011). The active elements of fertilizer are N, P and K. Improper use of fertilizer and unreasonable fertilization leads to wastage of considerable amounts of fertilizer. Loss of water and soil into the bodies of water aggravates environmental pollution; as such, many aspects of ecological system disorders are affected, leading to pollution of rivers and underground water sources. Despite large amounts of fertilizers applied, some elements needed by the plant remain insufficient. The soil deficiencies for nitrogen, phosphorus, potassium, sulfur, zinc, and boron are 87.9%, 46.1%, 72.4%, 86.1%, 61.3%, and 43.6%, respectively, in the major grain producing areas in the Songnen Plain in Heilongjiang Province (Li et al., 2010). The nitrogen brought into the surface water by farmland runoff accounts for 51% of the total nitrogen discharged into the bodies of water through human activities. Nitrogen loss in the application area is 3–10 times higher than that in the non-application areas. Large amounts of uncontrolled agricultural fertilizer use and large area loss have greatly affected the water quality of river basins but are difficult to control. According to a survey, the amount of fertilizers used per hm\(^2\) of the land has exceeded 400 kg per year in China but the utilization rate of chemical fertilizers is only 40%. A large amount of chemical fertilizer has entered the river through farmland runoff.
In China, large amounts of organochlorine pesticides are used. Organic chlorine compounds are difficult to degrade in the environment, and their half-lives in the bodies of water range from a few days to 20 years, with some even reaching 100 years. The half-life of these compounds in soil is approximately 10 years, and individual organic chlorine compounds can reach 500 years. Moreover, organic chlorine can damage the human immune system and cause cancer (Jiang et al., 2004).

Although the production and use of organic chlorine pesticides have been prohibited in China, their residues remain in the soil as a result of previous application. Analyzing the concentration of 666 and DDT in the soil samples collected from the Amur River Basin showed that the mean concentration of the former is $1.057 \times 10^{-3}$ mg/kg, ranging from $0.0037 \times 10^{-3}$ to $9.82 \times 10^{-3}$ mg/kg. The average DDT concentration is $0.87 \times 10^{-3}$ mg/kg, and the concentration range is $0 \times 10^{-3}$ to $6.11 \times 10^{-3}$ mg/kg. These values are lower than the concentrations of 666 in the Yangtze River Delta, Guangzhou, Tianjin, and so on.

From 1952 to 1984, the total usage of 666 was 108.9 kt in the Amur River Basin. From 1951 to 1984, the total usage of DDT was 4.9 kt. Crops mainly grow in the Songnen and Sanjiang Plains in the Amur River basin; as such, pesticide use is mainly concentrated in these areas. Moreover, 666 and DDT concentrations are the largest in Heilongjiang Province in the basin, followed by Jilin Province, and the Inner Mongolia Autonomous Region.

Emissions of 666 and DDT in soil in 2005 diminished compared with those in 1985 when 666 and DDT use was terminated in the Amur River Basin. These chemicals are mainly concentrated in the Sanjiang Plain and Songnen Plain as well as the main area nearby. In addition to individual regions, the emissions of 666 and DDT are almost zero in the northern and southeastern mountains (Liu, 2007).

From a short-term perspective, the use of pesticides has indeed increased the grain yield. However, from a long-term perspective, the practice has severely disrupted the ecological balance, severely damaging the wetlands, which are important parts of the ecosystem.
3. Suggestions for harmonious development of wetland and agriculture

Numerous industrial products, such as chemical fertilizers, pesticides, and insecticides, have been widely used through large-scale land reclamation and water conservancy projects to obtain high crop yields. The grain output has increased yearly. Many agricultural products satisfy the urgent need for food but also resulted in waste of resources, destruction of the ecological environment, and inferior quality of the products. Therefore, the old agricultural production modes that causes high pollution and discharges large amounts of waste should be abandoned; furthermore, an environment-friendly, green ecological agriculture production mode must be developed (Yao et al., 2014). Ecological agriculture is a production mode established upon basic ecological principles and laws of material cycle and energy transformation in the ecosystem; this technique features comprehensiveness, coordination, recyclability, and sustainability. This technique is also conducive to the realization of economic, ecological, and social benefits. We should maximize the application of agricultural high-technology systems and production modes fortified by modern and future energy sources as well as new materials, equipment, information technology, and biotechnology. The ecological and environmental friendly property of agriculture is confirmed by improving the connotation of agricultural science and technology and increasing the level of agricultural production management; these phenomena can lead to high value of the agricultural industry, eventually improving agricultural production capacity, level of industrialization, competitiveness, and comparative efficiency. High-value ecological agriculture, which includes the combination of the ecological agriculture and environment, features high yield, quality, and efficiency of agricultural products and the value of technology, market, and industry (Zhang et al., 2005).
A contradiction exists between the agricultural development and protection of wetlands in the Amur River Basin. This contradiction is not conducive to regional ecological security and expansion of the service function of the entire system. This contradiction also severely restricts the ecological functions of wetlands in this area. Regarding food safety, the cultivated land area should be maintained at a certain level. Considering regional ecological security maintenance and ecological service function, the area of the wetland should be continuously expanded. Therefore, we should establish an environment-friendly, green agriculture in the Amur River Basin. While ensuring food production, we should also increase the area of wetlands to curb their atrophy and functional degradation. Several specific recommendations are as follows:

3.1 Establish and perfect the laws and regulations of wetland conservation as well as strengthen publicity

Sound policies and regulations are key aspects of effective protection of wetlands and sustainable utilization of wetland resources. Protection and rational utilization of wetland resources in the area are important to establish effective wetland management policies. Thus far, evaluating the roles of current policies and existing regulations in the area of wetland protection, establishing and improving policies and regulations related to wetlands in a timely manner, and gradually establishing and rectifying the economic policy system are necessary; these practices can encourage and guide people to protect and use wetlands rationally and limit the destruction of wetlands under the overall economic operation mechanism of the utilization of land and resources. Such practices are also vital to clear the jurisdiction and administrative division of labor of the wetland management agencies in the form of laws and regulations and standardize their management procedures. In addition, the district should focus on the role of publicity and supervision of media, mass organizations, and research institutions. Regarding continuous improvement of the public awareness of the ecological environment, the law is the basis of the final analysis (Sun et al., 2006). To make people realize the importance of wetlands, establish their own awareness, and improve means to protect the wetlands, the government and relevant departments should increase publicity efforts and continue to strengthen people's understanding of the wetlands. Furthermore, course propagandas should be regularly conducted and everyone should be involved in the process to permanently address the problem. In the Amur River Basin, we should strongly implement the corresponding laws and regulations and promote the importance of wetland protection. Moreover, we should increase the number and scale of wetland protection areas and maintain the biodiversity. Converting farmlands from land areas is unsuitable for cultivation to wetlands. A rational resource environment ecological water conservancy system should be established, and a certain scale of wetlands should be maintained (Li et al., 2009).
3.2 Balance agricultural development and wetland protection

Wetland protection does not involve increasing the area of wetlands by converting farmlands. Considering the high demand for grains in China, the Amur River Basin, as a national commodity grain base, carries a lot of pressure and responsibility of producing grain. However, developing the basin in a disorderly manner and reclaiming it blindly for food production is not desirable. This practice can only temporarily increase the grain output, and in the long-term, the environment would gradually deteriorate; consequently, large areas of land will manifest desertification and salinization, thereby reducing soil fertility and grain production. Therefore, basing on the relationship between food production and wetland protection, we should increase the scientific research on wetland protection and set up a special research team. In view of the reasonable development of wetland, research should focus on attaining the equilibrium of development, utilization, and ecological protection. At present, the wetland area of the Sanjiang Plain is reduced and the surface water flow is severe, resulting in deterioration of the ecological environment. In view of the function of Sanjiang Plain Wetlands in maintaining water and ecological balance in the region, the authorities must carry out measures, such as establishing ditches and dams, returning farmlands to forest and grassland, construction of protected areas, and improvement of water conservancy systems. To ensure that ecological water requirement of wetlands are satisfied and restore and rebuild the wetlands, we should value, protect, and rationally develop and use resources in the Sanjiang Plain. The agricultural production and wetland environment during the period from the late 1970s to the early 1980s were more coordinated than the rest periods. The area of wetland and the wetland area of Sanjiang Plain were $870 \times 10^4$ hm$^2$ and $195 \times 10^4$ hm$^2$, respectively. This wetland area was 37% of the wetland area of Sanjiang Plain during the founding of the PRC. Under this restoration area target, according to the diversity of species and habitat, the number of plant species and the number of bird species in the Sanjiang Plain wetland could be restored to 70% and 80% of the amounts of the founding year of the PRC respectively, which shows that the ecological benefits of wetland restoration are significant (Wang Winter, 2006).

3.2 Balance agricultural development and wetland protection

The most important point of the ecological agriculture model is combining use and support and improving the utilization rate. According to a survey, large parts of the developed fields have low land utilization rate. We are not able to efficiently use the developed farmland and turn it into a low-yield field. In fact, the yield per mu of the farmland can be greatly improved compared with its original size after implementation of ecological agriculture. Therefore, we need to use
scientific methods, implement ecological agriculture, and rationally use existing resources, rather than blindly reclaiming new lands. The combination of the use and protection of farmland is crucial. Excessive farming can decrease soil fertility, resulting in land desertification and soil and water loss. Returning straw to the field is a typical model of ecological cultivation. According to the ecological principle, an ecosystem can be formed provided that basic components, such as non-ecological elements, producers, and decomposition, are available (Feng et al., 2012). According to traditional cropping patterns, the straw is burnt after grain harvest, thereby destroying the air environment. Moreover, the air quality indices sharply decrease in the northeast region during agricultural harvest. If straw is returned to the field, it can provide sufficient nutrients for the next crop, thereby recycling elements adequately. This practice not only improves soil nutrients and reduces fertilizer use but also efficiently avoids air pollution caused by burning of straw.

Another challenge is that crops are too simple in the current agricultural production mode in the Amur River Basin. Although rice flood control effectively prevents waterlogged lowland caused by excessive rainfall in summer, this technique exhibits limitations. Planting rice could solve problems but could only be followed by a single crop and consumes excessive amounts of land. Therefore, crop diversification must be incorporated in existing resources to realize three-dimensional and comprehensive output of agricultural products. Three-dimensional ecological agriculture is a management model for multi-species coexistence, configuration, energy recycling, material stereo-planting, breeding or stereo-cultivation, and stereo-breeding, which extend the benefits and avoid harm using biological interactions. Consequently, this process maximizes the use of space, combines different biological populations; such combinations include three-dimensional cultivation of peaches-strawberries, cucumber-bitter gourd, watermelon-pepper, and leek-cucumber (Wang, 2011; Han et al., 2008). This mode will not only greatly enhance the utilization of land but prevents excessive intake of single elements of the land caused by a single product; moreover, this method makes good use of space. From the ground to the top crops, a good use of space can save the land.

The agricultural model of heavy use of industrial fertilizers is highly undesirable. Widespread use of chemical fertilizers will not only cause pollution but is also a threat to food safety because of numerous harmful residual ingredients in crops from pesticides and fertilizers. To solve this problem, we can carry out the food chain planting and biogas ecological planting modes. These modes can greatly ease the use of industrial fertilizers by substituting with green biochemical fertilizers. This mode reduces the environmental pollution and guarantees the production of green and healthy agricultural and sideline products. This planting mode is built based on the energy flow of the ecosystem and the law of the circulation of materials; an example is the grain-pig-biogas-fish mode (Wang, 2011). Considering the amount of water in the rice field, we
can breed fish or shrimp in the rice paddy. Fish feces are the optimal natural fertilizer for rice. Moreover, rice husk can feed the fish and pigs. Pig feces can also be used in biogas power generation. Wastes generated from various links may be put to good use in such a cycle mode. Therefore, the waste used to needing extra money and energy to dispose could produce new value. This model links the aquaculture industry with the growing industry, taking the biogas fermentation as a link, biogas as energy, and biogas slurry and biogas residue as fertilizer, making the ecological system a virtuous circle (Liu et al., 2010; Chen et al., 2010; Luo, 2009).

Wetland resources from perennial or seasonal waterlogging are abundant and influenced by the river basin and closed flow and semi-closed flow terrains in the Amur River Basin. However, measures, such as drainage and flood control and using anti-wet early species, must be implemented because of the late history of the development and utilization of wetland resources in the north and the guiding ideology of drought. Thus, wetland agriculture slowly develops in the north. For effective scientific development and use of wetland resources in the region, we need to explore the internal mechanism of wetlands for agricultural production and the high efficiency and low consumption road of comprehensive development. The Northeast Institute of Geography and Agroecology and Chinese Academy of Sciences studied the wetland ecological model of agriculture in Baifa village, Helen County, Heilongjiang Province in the 1980s. A duplex mode of "rice, grass, fish, animal husbandry" has been established, and its energy flow, logistics, water and nutrient cycles and economic benefits have been studied. This mode provides a theoretical basis and practical experience for wetland agriculture development and control of similar climate zone. The ecological and economic benefits of different operation modes of wetland resources in the plains of northern northeast China were significantly different. Aquatic systems are optimized based on biological harmony with the environment, and production and consumption of main subgroups living body chain forming a ring; this process improves the energy conversion efficiency and material recycling rate and increases the economic efficiency (Han et al., 1990). Since 2003, Xingtu Liu et al. from the China Engineering Academy, carried out ecological restoration and rational use of research and demonstration to severely degrade beef heart hedging reed wetland. The team applied the principle of biological symbiosis and ecological material recycling to establish a complex ecological engineering mode of reed–fish (crab)–rice, and made significant socio-economic and ecological benefits. The restored reed wetlands, severely saline-alkali land, and the altered paddy field provided bait for fish and crabs. Fish and crabs can feed on the weeds that compete for space and fertilizer with the reed and the pests that are harmful to the reeds. The stool of fish and crabs can increase the fertilizer. The feeding activity can also loosen the soil and promote development underground reed stems, thereby improving the reed quality and yield. Moreover, a large number of submerged plants in the reed field also provided a good place to breed and avoid predators for fish and crabs.
3.4 Set up agricultural demonstration counties

The first and most intuitive effect of establishing ecological agriculture demonstration in counties is that we can greatly improve the level of agricultural production mode of demonstration counties, greatly boost productivity, and effectively promote local economic level. Second, the establishment of agricultural demonstration in counties could be regarded as propaganda by leading and demonstrating. The establishment of agricultural demonstration counties sets an example for the implementation and development of ecological agriculture and drives the surrounding counties and farms to achieve comprehensive ecological agriculture. We need to achieve this goal to have the agricultural demonstration counties as the core, then drive the surrounding counties and farms to achieve a comprehensive ecological agriculture. For example, for the construction of ecological agriculture in Dongguan, the coverage rate of the fruit tree reached 50% in the farm. The fruit trees in a radius of 10 miles emitted fragrance and showed a lively scene. In the establishment of ecological demonstration counties, we also need to take the demonstration county as the center to establish the powerful propaganda and education abilities and cause more farmers to understand the benefits of ecological agriculture. Concurrently, we can also carry out classes to improve farmers, such as the first batch of Ecological Agriculture Demonstration County during 1994 – 1998, which held a total of 1120 training classes, training personnel 160000 people (Ding, 2008). Through learning and training, the agricultural level of farmers has been greatly improved and the ecological agriculture technology seamlessly transformed into productive forces. Such a cycle can improve the living standard of farmers. For example, the quality of workers has been significantly improved in the process of ecological agriculture construction in Jingshan County, wherein the field of rural wealth now expands from low-to high-level. There are more than 1000 farmers that obtained intermediate and junior technical titles in the county, 1/3 of the rural labor force have mastered the 1 – 2 levels of practical technology and knowledge of ecological agriculture (Ding, 2008).

3.5 Develop new technologies and improve the management level of wetland agriculture ecosystem

To exert the function of wetland agriculture ecosystem, we need to improve research on wetland agriculture ecosystem, work out the strategy of comprehensive development and rational utilization of wetland, and strategize to protect the wetland species resources and water and soil resources, to establish a rational wetland agriculture ecological structure and promote the development of wetland agriculture ecosystem. In order to construct and develop wetland agriculture ecosystem, we need to make the comprehensive development plan rely on the
reasonable macro decision, and continuously develop the management technology of wetland agriculture ecosystem that adapt to the natural, economic and social conditions (Fang, 2003). To provide a scientific basis for the protection and management of wetland agriculture, we need to strengthen the basic and applied technology research on the protection and rational utilization of agricultural resources of wetlands (Liu et al., 2010) by actively exploring the modes of agricultural protection, restoration, and sustainable use of wetland by strengthening scientific and technological supports. Special attention should be paid to developing a variety of biological resource utilization technologies and a variety of ecological technologies that are conducive to reducing the input of external materials and maintaining the stability of the system, as well as the corresponding technologies to improve agricultural productivity. In addition, further increasing the scientific research strength of the rational use of wetland resources in the Amur River Basin is necessary to improve the existing wetland ecosystem mode and improve and create high quality and efficient ecological agriculture modes (Yao & Lv., 2008).

3.6 Promote the harmonious development of wetland and agriculture

The harmonious development of wetlands and agriculture can provide a solid guarantee for the ecological and food security in China. There are good examples of the harmonious development of wetland and agriculture in China, such as the planting and breeding mode in Guoji and Sangji fish bonds in the Pearl River Delta (Zhong, 1980; Han et al., 1990); the seedling growth mode of the fishery production in lake wetlands; the three-dimensional ecological planting and breeding mode of rice–duck and rice–fish in the paddy fields in south China; and the seasonal protection management mode of the core area being explored by the Wetland Nature Reserve. In addition, due to the unique function of wetland resources, the development of characteristic agriculture in the development, utilization, and protection of wetlands can realize the value of wetlands. We can give full play to its indirect use value, to make the protection and utilization of wetland resources harmonious (Liang et al., 2009). This can increase the diversity of wetland agriculture and ecosystem to make full use of the advantages of the wetland biological resources, continuously improve the management mode of wetland agriculture, and construct the compound ecosystem management mode of the regional characteristics (Yang et al., 2001). Therefore, on the basis of promoting the construction of ecological civilization, we need to adhere to the basic state policies of conserving resources and protecting the environment, and it is necessary to explore and implement the harmonious development model of wetland and agriculture, actively try special agricultural production, and continuously improve the management mode for wetland agriculture, thereby creating a good production and living environment for local people and contributing to global ecological security.
4. Summary

Considering the wetland changes in the Amur River Basin, a large number of agricultural activities and the irrational patterns of agricultural production caused severe damage to the wetland ecosystem. Wetlands are important ecosystems, and they are inhabited by a large number of animals and plants. As a result of the increasing demand for food secondary to population growth, there is contradiction between agricultural land and wetlands. On the one hand, it is not desirable to simply pursue the high yield of agriculture, which leads to the great destruction of wetlands and the environment. On the other hand, the protection of wetlands is also needed to ensure that the demand for food and agricultural products are met, and we cannot simply return farmland to wetland. Therefore, we should increase scientific research and investment to find a practical way to balance wetlands and farmlands, and make it not only to protect the wetland, but also to satisfy the demand for food. To coordinate the contradiction between agricultural land use, food production, and environmental protection, developing the economy under the premise that the ecological environment should not be vicious circle; therefore, rational control is significant in the process and scale of converting wetlands into farmlands, and establishing the wetland ecological agriculture of sustainable development to ensure food security and achieving the rational development and utilization and protection of wetland resources. Therefore, it is imperative to develop an environmentally friendly green agricultural production mode in the Amur River Basin. The production mode can improve efficiency, and the impact on the natural environment can be minimized. Moreover, it can better protect the wetlands through a virtuous cycle.
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