DOI: 10.12398/j.issn.2096-7217.2025.04.006

Research on the development of electric agricultural machinery technology based on patent information

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Abstract: This study takes the patent information of China's electric agricultural machinery technology as the research object, and uses patent measurement analysis method and visual analysis tools to carry out statistical analysis and comparative research on the relevant patent information from the perspectives of annual patent applications, patent structure, technological key, main applicants, patent layout, technology lifecycle and so on. The research results show that China's electric agricultural machinery technology innovation is developing rapidly, and the patent categories are mainly utility model and invention patents, and the proportion of invention patents is lower than utility model patents. Universities are the most important innovation subjects in this field, and technology research and development focuses on IPC (international patent classification) subcategories such as A01C (seeding, fertilization), B60K (power, transmission), and A01D (harvesting, mowing). Jiangsu Province and Shandong Province rank the top 2 in the number of domestic patent applications, and the United States and Japan are the two countries with the most layout in China. At present, the growth of electric agricultural machinery technology is weak, but the new technology has strong features, there is no sign of maturity, and it does not have signs of technological aging and still has greater development potential. The results of the study can provide information reference for clarifying the status quo, characteristics and development trend of China's electric agricultural machinery technology innovation.

Keywords: China electric agricultural machinery; technology development; patent analysis; technology lifecycle; IPC

CLC number: S24　　**Documents code:** A　　**Article ID:** 2096-7217 (2025) 04-0064-09

LIU Qin, HU Lianglong, GAO Ya. Research on the development of electric agricultural machinery technology based on patent information [J]. Journal of Intelligent Agricultural Mechanization, 2025, 6(4): 64－72

刘勤, 胡良龙, 高雅. 基于专利信息的电动农机技术发展研究[J]. 智能化农业装备学报(中英文), 2025, 6(4): 64－72

0　Introduction

With the promotion of the rural revitalization strategy, green development has become the main theme of China's modern agricultural development. As the main tool of agricultural green production, electric agricultural machinery does not burn fuel, which can greatly reduce the environmental pollution during operation. Electric agricultural machinery has been explored and developed in China for some years, and many universities, research institutions and enterprises are developing electric agricultural machinery.

Electric agricultural machinery refers to agricultural equipment that uses electricity or batteries as energy and power, which includes both agricultural machinery that uses electricity as energy, such as threshing machines driven by electric motors, and agricultural equipment that uses batteries instead of fuel engines as energy to drive electric motors to complete operations. The electric agricultural machinery in this study also includes

Received date: 2024-07-31　　**Revised date:** 2024-10-17

Foundation item: Special Fund for Basic Scientific Research Business Expenses of Central Public Welfare Scientific Research Institutions(S201947)

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agricultural equipment containing electric components.

Technological innovation and patents are closely interrelated, and patents are not only an important output of technological innovation, but also an important measurement index of technological innovation activities[1-3]. At present, there is no literature on the research and analysis of the development of electric agricultural machinery technology in China from the perspective of patents. Through the in-depth analysis of relevant patent literature, this study aims to grasp the overall development trend and competition pattern of the technology in this field, clarify the technological hotspots, and provide relatively intuitive intelligence support for the next step of technological research and development and technological cooperation.

1　Data and method

Patents cover more than 90% of the world's latest scientific and technological intelligence, which is 5-6 years earlier than the information provided by general publications[4-6]. As an important carrier for recording technological information, patent literature is considered as an important source of data for the analysis and research of technological development[7-9]. In this paper, we adopt the bibliometric analysis method to measure, summarize and visualize the information of patent applications, applicants, IPC numbers, technology themes and other indicators, so as to reveal the technological strength of each innovation subject, identify the technological evolution track, discover specific technological trends, avoid "technological traps", and seek the potential fields of technological innovation population and technology application.

The research object of this paper is the patent literature in the field of electric agricultural machinery in China, and the data comes from the patent database of China Intellectual Property Office. The categories of searched patents include invention patents, utility model patents and appearance design patents. The keywords searched were "electric and (agricultural machinery or agricultural equipment or tractor or agricultural vehicle or agricultural product processing machinery or agricultural irrigation machinery or animal husbandry machinery or agricultural transport machinery)".

2　Analysis of results

2.1　Trends in applications

As of December 31, 2023, after manually screening and eliminating irrelevant data, 3 340 valid patent data in the field of electric agricultural machinery were finally retrieved, including application time, the number of applications, applicant, patent category, IPC number, technological abstract and other information.

By counting the number of patent applications for a certain technology over a period, the overall development trend of the technology can be roughly judged. From Figure 1, from 1985 to 2006, the annual number of patent applications in this field was relatively small, maintaining below 30, indicating that the development of technology during this period was still in the early stage. From 2007 to 2012, the number of patent applications showed a slight growth trend. From 2013 to 2020, the number of patent applications increased rapidly, and the growth rate accelerated significantly, with an average annual growth rate of 16.55%. The number of applications in 2020 reached 371, the highest in history, indicating that the technology research and development in this field is heating up significantly, and there are more innovative subjects and inventors joining in the rapid development stage. From 2021 to 2023, the number of patent applications in this field declined, especially in 2023, the decline is obvious, and there is sign of entering a downward trend.

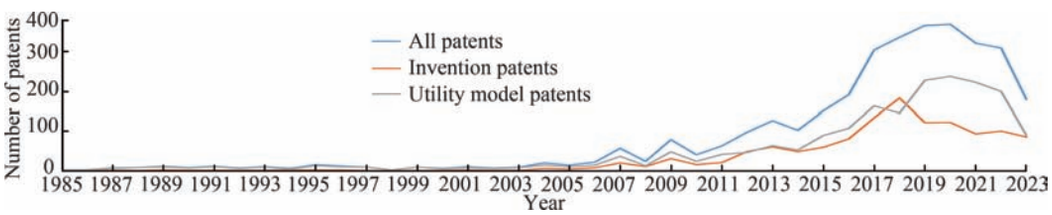


Figure 1　Annual trends in patent applications

2.2 Patent structure

The categories of Chinese patents include invention patents, utility model patents and design patents. Different patent categories represent different levels of technological innovation[10-11]. Invention patents can best reflect the ability of technological innovation activities, and utility models are of great practical value, although their creativity and technological level are lower than that of invention patents. The appearance design is completely different from the above two. It is not a technological solution[12-13], but a product style designed for the purpose of promoting application and occupying the market. It is produced at the stage of the transformation of innovative achievements into products, and is an indicator that can comprehensively understand the real situation of the implementation and application of patent achievements[14-15]. From Figure 2, the patents in the field of electric agricultural machinery are mainly utility models and invention patents. Among them, utility models account for 60%, invention patents account for 38% and appearance designs account for 2%. Compared with utility models, the proportion of invention patents is low, indicating that the technological innovation ability in this field needs to be improved. As shown in Figure 1, there is a difference in the annual trend of utility model and invention patent applications. The peak of invention patent applications appeared in 2018, followed by a turning point and the number of applications declined, while the peak of utility model patents appeared in 2020, 2 years later than that of invention patents, and the number of applications declined thereafter.

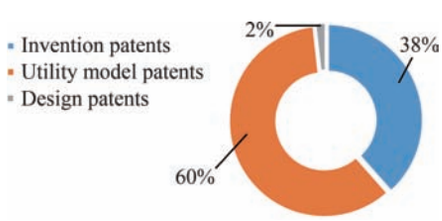


Figure 2 Patent structure

2.3 Technological key

IPC is currently the only common classification tool for patent documents in the world, which adopts a five-level classification principle of functionality as the primary and applicability as the secondary, namely, part, category, subcategory, large group and small group[16-17]. The IPC's categories and groups from the patent data set are usually active areas for technology research and development[18]. According to the IPC subcategory, this study categories and statistically analyzes the patents in the field of electric agricultural machinery and explores their technological key and efficacy. We found that the R&D hotspots in this field are concentrated in IPC subcategories such as A01C (seeding, fertilization), B60K (power, transmission), A01D (harvesting, mowing), A01M (plant protection), A01G (pruning), B62D (steering), etc., specifically:

1) In A01C, the research involves electric rice transplanters, self-propelled electric film-laying and seeding machines, electric quantitative seeding machines for small diameter vegetable seeds, intelligent variable fertilization devices, and electric crawler-type facility vegetables precision seeders, etc. Among them, the electric rice transplanter is equipped with a splitting mechanism and a transplanting mechanism, which can separate the seedlings, so that other seedlings will not be taken out when transplanting, thus ensuring the survival rate of seedlings. The self-propelled electric film-laying seeding machine solves the sowing inconvenience caused by being far away from the tractor. The electric quantitative seeding machine for small diameter vegetable seeds can achieve quantitative sowing of small-size vegetable seeds and improve the efficiency and accuracy of sowing. The intelligent variable fertilization device can adjust the amount of fertilizer according to the degree of fertility of different lands. The electric crawler-type facility vegetables precision seeder can sow all kinds of pelletized vegetable seeds, with adjustable sowing depth, row spacing, compaction degree, and has the function of seed leakage detection.

2) In B60K, the research involves the front and rear axle dual-coupled power system of electric tractors, oil-electric hybrid power continuously variable transmission system, three-motor power control system, power distribution control device, chassis, series/parallel/hybrid system, battery thermal management system, and drive system for converting oil to electricity in agricultural machinery. Among

them, the front and rear axle dual-coupled power system of electric tractor can meet the power demand of medium and large horsepower electric tractor under different operating conditions. The oil-electric hybrid power continuously variable transmission system can achieve the stepless speed change of the tractor. The three-motor power control system can achieve the goal of driving different rotating devices through different motors without power coupling. The battery thermal management system can recycle the waste heat of battery pack and make use of the heat of the battery pack to heat the cockpit. The drive system for converting oil to electricity in agricultural machinery can gradually convert the existing combustion-engine agricultural machinery into electric agricultural machinery in order to reduce the carbon emissions of agricultural machinery.

3) In A01D, the research involves crawler-type electric corn harvesters, portable electric pineapple harvesters, adjustable solar lawnmowers, electric shear-type Sichuan pepper picking tools, small fruit picking unmanned aerial vehicle (UAV), electric vegetable bundling mechanism and so on. Among them, the crawler-type electric corn harvester can be adapted to the harvesting operation on different slopes, and is also convenient for the operation in hilly areas. The electric shear-type Sichuan pepper picking tool solves the problem of high labor intensity, long time-consuming, high cost, and low efficiency in manual picking of Sichuan pepper. The small fruit picking UAV can synchronously achieve the shear and cut, and the clamp tightness can be adjusted. The electric vegetable bundling mechanism can realize the flexible bundling of vegetables, and it can effectively avoid the damage to the vegetables during the bundling process.

4) In A01M, the research involves electric sprayers, electric flower nursery pesticide spraying vehicles, highland gap electric plant protection and fertilization all-in-one machines, vehicle-mounted electric grape pesticide-spraying devices, pesticide-spraying system for electric tractors, and low-center gravity electric crawler remote control sprayers, etc. Among them, the highland gap electric plant protection and fertilization all-in-one machine can spray two kinds of herbicides at the same time, so as to achieve multi-purpose use of one machine. Vehicle-mounted electric grape spraying device can solve the problem that the existing large-scale grape spraying machinery is easy to entangle the grape vines. The pesticide-spraying system for electric tractor can make the sprayed liquid to meet the demand of the spraying distance, and achieve the uniformity of pesticide-spraying. The low-center gravity electric crawler remote control sprayer has the characteristics of good trafficability, low-center gravity of chassis, and small spray rod size, it can achieve electrostatic spraying on target through the control system, which greatly improves the spraying efficiency and intelligent level, and reduces the waste of pesticide.

5) In A01G, the research involves electrically driven fruit tree pruning equipment, self-propelled orchard electric operation platforms, etc. Among them, the electrically driven fruit tree pruning equipment uses battery packs as the power source, which can realize the efficient use of energy and the modular application of agricultural machinery. The self-propelled orchard electric operation platform can complete fruit tree pruning, pruning and fruit picking operations in the self-propelled process.

6) In B62D, the research involves hydraulic steering mechanism, universal electric steering wheel for automatic navigation, topology of intelligent driving electric tractor with supercapacitor assisted energy, steering control method for wheel-edge electric tractor, and so on. Among them, the hydraulic steering mechanism has a large steering torque and good load effect. The steering control method for wheel-edge electric tractor can control the rotational speed stability of the electric tractor in various terrain environments, thus improving the flexibility of the electric tractor. There is a kind of electric tractor that uses four walking motors to achieve walking and steering and adopts one operating motor to achieve the output of rotary power and hydraulic power, which eliminates the complex steering mechanism and differential transmission mechanism. There is also a kind of electric tractor that uses two different steering methods, manual and automatic, and has the function of steering reset.

2.4 Main applicants

Table 1 shows the ranking of patent applications and the average number of patents filed by the main

applicants. It is generally believed that the lower the average number of patents, the stronger the technology reserve capacity and R&D activity of the patentee, and vice versa[19-20]. It can be seen from Table 1 that the innovation subjects of patents in the field of electric agricultural machinery are universities, institutes, and enterprises, and 7 of the top 10 applicants are universities, one is a research institute, and 2 are enterprises. Henan University of Science and Technology, which ranks first in the number of applications, entered the field of electric agricultural machinery in 2006, and then had patents issued every year, showing strong innovation activity and strong technology reserve capacity. This applicant's research content is relatively extensive, involving the topology of intelligent driving electric tractor with supercapacitor assisted energy, the series, parallel, and hybrid power system of intelligent tractor, the adaptive control system of tractor electric suspension, the dual-motor transmission device of electric tractor, the integrated thermal management system, the electromagnetic immunity test system of the whole vehicle, the electro-hydraulic suspension system, and the agricultural wind and photovoltaic energy storage charging and discharging microgrid system, etc. In terms of the average number of patents, universities and research institutes have a relatively low figure while enterprises have a higher one, indicating that enterprises' innovation vitality and technological reserve capacity need to be improved.

It is worth mentioning that Luoyang Intelligent Agricultural Equipment Research Institute Co., Ltd., although its average number of patents is the highest, it has produced 1 appearance patent in 2022, involving an electric tractor (36.8 kW hub motor), indicating that this applicant has taken the lead in entering the market, which is also consistent with the actual market situation. This patented product has been unveiled at the 2023 National Agricultural Machinery Exhibition and is expected to take the lead in national promotion and application.

Table 1 Main applicants

Rank	Applicant	Number of patents	Number of inventors	Average number of patents
1	Henan University of Science and Technology	68	122	0.56
2	Luoyang Intelligent Agricultural Equipment Research Institute Co., Ltd.	60	55	1.09
3	Northwest A&F University	51	155	0.33
4	Jiangsu University	42	112	0.38
5	China Agricultural University	41	152	0.27
6	Northeast Agricultural University	34	82	0.41
7	Kunming University of Science and Technology	30	76	0.39
8	Nanjing Agricultural University	29	52	0.56
9	Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs	28	101	0.28
10	Weichai Leiwo Smart Agriculture Technology Co., Ltd.	22	44	0.50

Note: Average number of patents = number of patent applications filed by the applicant/number of inventors by the applicant

2.5 Patent layout

From the domestic perspective of China, as shown in Figure 3, Jiangsu, Shandong, Henan, and other provinces are the top 10 provinces with the largest number of patent applications. Among them, important applicants in Jiangsu province include Jiangsu University, Nanjing Agricultural University, and Jiangsu Yueda Intelligent Agricultural Equipment Co., Ltd., etc., important applicants in Shandong Province include Weichai Leiwo Smart Agricultural Technology Co., Ltd., and Shandong Agricultural University, etc., and important applicants in Henan Province are Henan University of Science and Technology, Luoyang Intelligent Agricultural Equipment Research Institute Co., Ltd., and First Tractor Co., Ltd.. From the foreign perspective, since 1987, 13 countries and

regions, including the United States, Japan, Italy, Germany, Denmark, the Netherlands, Russia, Australia, Canada, Finland, the United Kingdom, Sweden and Macao, China, have applied for patents in China, with a total of 57 applications. The United States (25 applications), Japan (9 applications) and Italy (5 applications) ranked the top 3 in terms of the number of patent applications. Deere & Company and CNH USA, LLC were the top 2 applicants in the United States, and Kubota Co., Ltd. and Iseki & Co., Ltd. were the top 2 applicants in Japan. In 1987, the German Agricultural Machinery Development Consortium invented an electro-hydraulic lifting mechanism adjustment device. In 2013, Deere & Company in the United States proposed an electric lawn tractor power management system and method, and in 2020, the company also invented a power-shift gearbox with electric assistance.

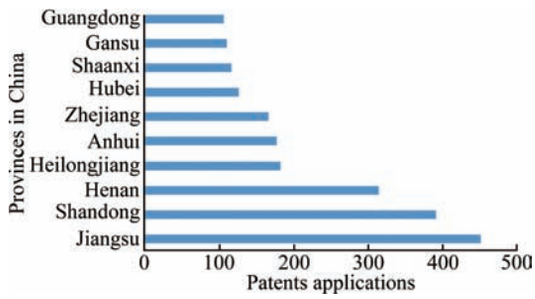


Figure 3　Top 10 provinces with the highest number of patent applications in China

2.6　Technology lifecycle

The patent technology lifecycle analysis method is one of the methods in quantitative analysis of patents. The development of patented technology generally goes through four stages: technology introduction period, development period, maturity period and elimination period.

Table 2　Parameters of patent statistics

Parameter	Parameter interpretation	Calculation formula	Significance of statistics
V	Technology growth rate	$V=a/A$	Increasing value of V indicates the stronger the technology growth
N	New technology features coefficient	$N=(V^2+\alpha^2)^{1/2}$	Increasing value of N indicates the stronger the new technology features
α	Technology maturity coefficient	$\alpha=a/(a+b)$	Decreasing value of α indicates that the technology is becoming more mature
β	Technology aging coefficient	$\beta=(a+b)/(a+b+c)$	Increasing value of β indicates that the technology is becoming more outdated

Note: a: the number of invention patent applications in that year. b: the number of utility model patent applications in that year. c: the number of appearance design patent applications in that year. A: the cumulative number of invention patent applications dating back to 5 years.

In this study, the development stage of China's electric agricultural machinery technology is measured by calculating the technology maturity coefficient (denoted by α), the technology aging coefficient (denoted by β), the technology growth rate (denoted by V) and the new technology features coefficient (denoted by N). The significance of statistics of each parameter is shown in Table 2.

Through calculation, it is found that the fluctuation range of V, N, α, and β values from 1987 to 2000 is relatively small, and the trend change is not significant, so the horizontal coordinate of Figure 4 takes 2001 as the starting point. From the perspective of technology growth rate V, from 2001 to 2018, the fluctuation is large, and from 2018 to 2023, the V value shows a slight decline, indicating that the technology growth in this field is currently weak. From the perspective of new technology features coefficient N, from 2001 to 2018, the change trend of N value is roughly similar to that of V value, basically fluctuating around 0.5, and from 2018 to 2023, the change trend of N value is also similar to that of α value, with a slight decline at first, followed by turning upwards, indicating that the new technology features are still strong, and it still has a large potential for development. From the perspective of technology maturity coefficient α, the α value showed a slight upward trend from 2003 to 2018, indicating that with the growth of new technologies, the attractiveness of the technology gradually appeared, the number of innovation subjects and inventors involved increased day by day, and the number of patent applications continued to grow. From 2019 to 2023, the α value first dropped

slightly and then turned upwards, indicating that although technology has developed rapidly, there is no signs of maturity.

From the respective technology aging coefficient β, since the produce of appearance patents in this field is very low, the β value always fluctuates around 1.0, and there is no increasing trend, indicating that the technology has not yet become obsolete, and does not yet have the characteristics of technology aging.

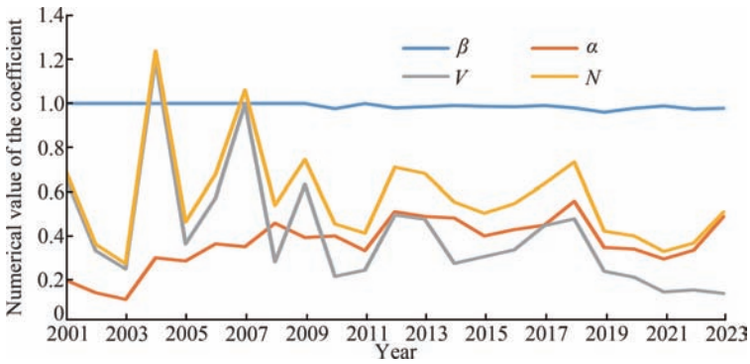


Figure 4 Technology lifecycle

3 Discussions

From the annual application trend of patents, the technological development in this field is on a downward trend, but the results of the analysis of the technological lifecycle show that the features of new technology are still strong, the technological development has not reached mature state, and it does not yet have the characteristics of aging. The analysis results of the two aspects seem to be somewhat contradictory, but after further analysis of the patents structure, it is found that, from 2001 to 2023, the proportion of invention patents in the total patents has not increased significantly, basically fluctuating between 0.3 and 0.5, and thus does not show the characteristics of technology maturity. The proportion of appearance design patent applications in all patents is very small and varies little, basically running between 0.02 and 0.04, so there is no sign of technology aging. Since design patents are often not involved until after patent exploitation has entered the market, its lower amount products can also explain to some extent why the features of new technologies in this field are still relatively strong.

It is precisely because there is still room for the development of electric agricultural machinery technology that can be actively avoided for technologies with concentrated patents to prevent repeated research. There are three suggestions to promote the development and transformation of technology. Firstly, it is necessary to combine technologies in other fields for integrated innovation and improve the overall progress of technology. Secondly, it is necessary to focus on the collection, analysis and utilization of information on disclosed or expired patents, especially the reuse of expired patents. The expired patents can be used free of charge, patent invalidation does not mean the loss of value. Many expired patents still have high technological content and market value are still very high, and if this part of the resources is reasonably reused, there is no need to pay a huge amount of patent transfer fees, which can maximize the saving of development time and funds. Thirdly, it is necessary to strengthen the cooperation among patent applicants, strengthen joint research and industry-university-research cooperation, give full play to their respective advantages, and jointly promote technology diffusion, knowledge-sharing and effective transformation of achievements.

4 Conclusions

This study uses patent analysis method to visually analyze the development trend and characteristics of China′s electric agricultural machinery technology from a total of six dimensions, namely, annual patent applications, patent structure, technological key, main applicants, patent layout, and technology lifecycle, and the study concludes as follows.

1) The field is in a relatively active development

stage of technological innovation, the ability and level of technological innovation have been steadily improved, and the features of new technologies are still relatively strong. At this stage, the focus of development is still on the continuous improvement of technological innovation level, and it will take time for new technologies to be widely applied.

2) The patents in this field are mainly utility model and invention patents. Although the number of invention patent applications has grown rapidly in recent years, the proportion is still relatively low, the overall technological content is still not high, and the technological development has not yet reached a mature state.

3) The main patent applicants in this field are mainly universities, and compared with enterprises, universities have significantly stronger innovation activity and technology reserve ability. Therefore, it is necessary for enterprises and universities to strengthen industry-university-research cooperation and promote technology upgrading.

4) The technology research and development in this field focuses on IPC subcategories such as A01C, B60K, A01D, etc., and the technological hotspots involve electric sowing, electric fertilization, electric spraying, electric harvesting, electric mowing, electric pruning, and power devices, transmission devices and steering systems of electric agricultural machinery.

5) In terms of patent layout, from China's domestic point of view, Jiangsu, Shandong, Henan and other 10 provinces are the TOP 10 in the number of patent applications, the United States and Japan are the two foreign countries with the most layout in China, Deere & Company of the United States and CNH USA, LLC, Japan's Kubota Co., Ltd. and Iseki & Co., Ltd. are very active in innovation.

6) In terms of technology lifecycle, the current technology growth in this field is relatively weak, but the new technology features are still relatively strong and still have greater development potential, and there is no signs of maturity, and do not have the characteristics of technology aging.

The above findings provide intelligence support for understanding the current development status of the electric agricultural machinery industry and finding technology gaps. In the future, deeper analysis and mining of patent data is still needed to provide better support for industrial development.

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基于专利信息的电动农机技术发展研究

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摘要：以中国电动农机技术专利信息为研究对象，利用专利计量分析方法和可视化分析工具，从专利年度申请量、专利结构、技术关键、主要申请人、专利布局、技术生命周期等角度对相关专利信息进行统计分析和比较研究。研究结果表明，中国电动农机技术创新发展迅速，专利类别以实用新型和发明专利为主，发明专利占比低于实用新型专利。高校是该领域最重要的创新主体，技术研发重点集中于A01C、B60K、A01D等IPC小类，江苏省和山东省是国内申请专利量前2位的省份，美国、日本是在中国布局最多的两个国家。目前电动农机技术生长性偏弱，但新技术特征较强，还没有出现成熟的迹象，尚不具备技术衰老的特征，仍具有较大的发展潜力。研究结果可为明晰中国电动农机技术创新现状、特点及发展趋势提供信息参考。

关键词：中国电动农机；技术发展；专利分析；技术生命周期；IPC