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Agris category code: U30, C30

Presence of nanotechnology in agriculture: bibliometric approach

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ABSTRACT

Increasing number of scientific publications points to quick developments in the field of nanoscience and nanotechnology. Nanotechnology offers potentials of unimaginable proportions. Innovative possibilities present themselves in many areas of human activity, including agriculture, for example in precision farming, reduction of pollution and increasing crop yields. We bibliometrically assessed interactions between nanotechnology and agriculture. With co-word analysis in particular, we examined aspects of agro-nano applications related to plant protection. In order to analyze and map the structure of knowledge, we employed selected terms from a general citation database Web of Science (WOS) as well as specialized bibliographic database CAB Abstracts which covers life sciences with a special emphasis on agriculture. Our thematic maps (visualization) present some principal themes and relations among them. Pesticides, biosensors and detection are the main keywords in the network of words from article titles and network of the KeyWords+. Analysis of controlled terms (descriptors, classification codes) from CAB Abstracts in connection with pesticides shows two important directions of research: pollution and environmental topics, and topics related to human health, experimental animals and related.

Key words: bibliometrics, scientometrics, co-word analysis, nanotechnology, agriculture, pesticides, databases

IZVLEČEK

UPORABA NANOTEHNOLOGIJE V KMETIJSTVU: BIBLIOMETRIČNI PRISTOP

Naraščajoče število znanstvenih objav kaže na hiter razvoj področja nanoznanosti in nanotehnologije. Nanotehnologiji pripisujejo danes potencial neslutenih razsežnosti. Inovativne možnosti reševanja aktualnih problemov se kažejo na vseh področjih človekovega delovanja, s ciljem preciznega kmetovanja, zmanjšanja onesnaževanja in povečanja pridelka, tudi na področju kmetijstva. V našem delu smo prepletanje nanotehnologije s področjem kmetijstva bibliometrično ovrednotili. S sobesedno analizo smo proučili predvsem tisti vidik agro-nano aplikacij, ki se nanaša na fitofarmacevtska sredstva. Pri analizi in kartiranju strukture znanja smo uporabili različne ključne besede iz splošne zbirke WOS in specializirane zbirke CAB Abstracts, ki zajema širše področje kmetijstva. S tematskimi kartami smo prikazali najbolj poudarjena vsebinska področja in relacije med njimi. Osrednje ključne besede v omrežju besed iz naslovov člankov in v omrežju KeyWords+ se nanašajo na fitofarmacevtska sredstva, biosenzorje in detekcijo. Analiza deskriptorjev iz zbirke CAB Abstracts izpostavi predvsem dve pomembni smeri raziskav; onesnaževanje oziroma okoljske študije ter vsebine, ki se nanašajo na zdravje človeka, poskusne živali in s tem povezane modele proučevanja.

Ključne besede: bibliometrija, scientometrija, sobesedna analiza, kmetijstvo, fitofarmacevtska sredstva, nanotehnologija, bibliografske podatkovne zbirke

1 INTRODUCTION

Our era is marked by the transition towards the knowledge society. New technologies, such as biotechnology, nanotechnology and information technologies are at the forefront, promoting development in other areas (Roco and Bainbridge, 2002). Nanotechnology in particular is hailed as the new technological revolution, which has potentials to influence the society more than the industrial revolution. As indicated by Wood et al. (2003) "it is so profound that it will touch all

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aspects of economy and society". Substantial financial resources are allocated to research and development in this field (National …, 2011). The concept of "nano" represents something very small. Nanoparticles, whose specific properties nanotechnology exploits, are those small pieces of material, in which at least one dimension encompasses less than 100 nm (Commission ..., 2011). The very small size of these particles gives reason for very specific physical, chemical and biological properties. In comparison with the particles in larger dimensions, the nanoparticles are more chemically active, which can be favourable, if some chemical reaction is desirable, or negative if it is not. Although nanomaterials (natural or intentionally produced) are already present in many aspects of our life, the understanding its potential toxicity is still in its infancy (Tarver, 2006; The potential ..., 2009). Regulations governing the risks to human health and environment are very inadequate (Cush et al., 2012).

Employing innovative approaches nanotechnology has opened up new possibilities for the tackling of problems related to food safety and human health. In conventional agriculture intensive use of agrochemicals pollutes soil, groundwater as well as crop products. The use of encapsulated nanomaterials can reduce potentially toxic agrochemicals by employing controlled delivery (e.g. quick-release of agrochemicals, moisture-release etc.). Nanotechnology also has the capacity to decompose harmful components (Manjunatha et al., 2016). The reason is in specific characteristics of nanoparticles whereby, due to the small size of particle and consequently larger surface area, different systemic activity, solubility and mobility is reached. It has been predicted that nanotechnology will completely transform food industry in the future, including processing, packaging, and therefore also consumption (Tiju in Morrison, 2006; Rai in Ingle, 2012). The applications of nanotechnology in the field of agronomy have been summarized by various authors (Nanoscale …, 2003; Opara, 2004; Scrinis and Lyons, 2007; Ruffini Castiglione and Cremonini, 2009; Ghormade et al., 2011; Misra et al.., 2013; Huang et al., 2015: Manjunatha et al., 2016) as follows:

- controlled release of nano-agrochemicals used in plant nutrition and protection (also growth hormones or herbicides) and subsequent reduction of toxicity and environmental pollution (less loss through leaching or leaking),
- controlled delivery of genetic material to plant cells due to the small size of nanoparticles (molecular treatment for development of plant resistance to stress, pests or diseases),
- detection of different needs of plants connected with nutrients, diseases or pesticide residues by sensitive sensors,
- monitoring soil/environmental conditions and plant growth with sensors,
- detoxification of pesticide (herbicide) residues (e.g. atrazine, triazine); to avoid limitations in the selection of crops in rotation.

Science has created a huge body of scientific and technological data, information and knowledge in connection with nano technologies. As is evident in Figure 1, the number of records with general "nano" content has been constantly growing, especially in recent years. Similar increase of this topic, in relation to plant protection and fertilizers, has also been noticed by Gogos et al. (2012).

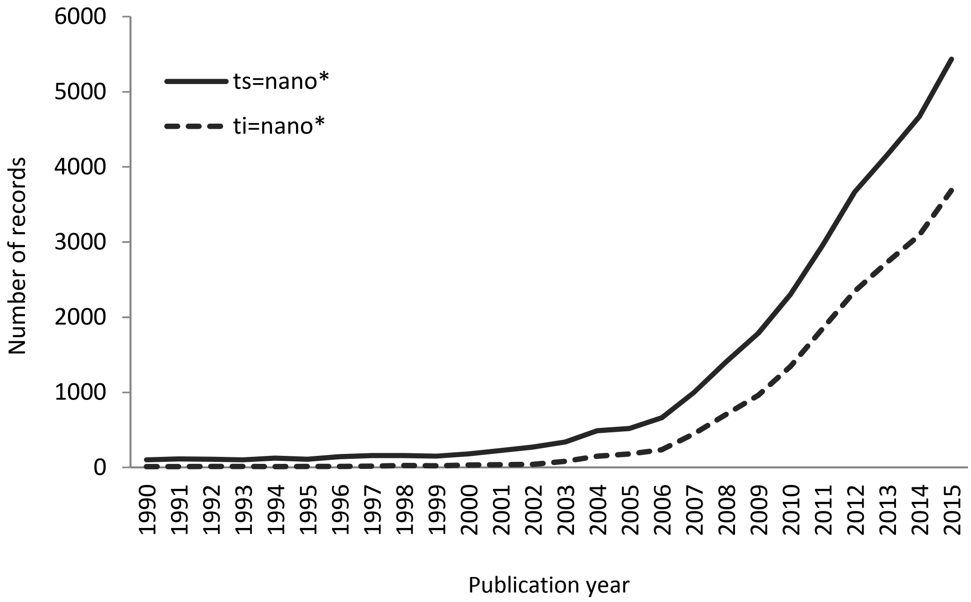


Figure 1: Number of records found in WOS regarding the search word-root nano* in an article title (ti), and records found by nano* in topic field (ts)

Fast development and promising scientific discoveries in the field of nanoscience and nanotechnology has also attracted attention of information science, especially bibliometrics. Thus, this field has become a model subject in many studies of this kind. Huang et al. (2011) identified more than 120 such studies. Much information is now available, however, tracking, monitoring and mapping thereof in an ever-changing system of scientific discoveries has become a very complex task. Using bibliometrics we can thus evaluate development of science by studying different models based on topics, authors, institutions, countries, etc. in a comprehensible way through quantitative studies, statistical analysis and graphical vizualisation.

Co-word analysis is a bibliometric technique which can identify topics and relations among the topics. This method uses patterns of co-occurrence of words or phrases. This helps to understand associations between various concepts within a subject area. Namely, appearance of two keywords or phrases within the same document shows the relationship between topics to which they relate (Cambrosio et al., 1993).

In this work we intend to assess relations between nanotechnology and agriculture. Since the most important part of agro-nano applications is related to pesticides, as reported in literature (e.g. Khot et al., 2012), we analyzed more specifically this particular area. We aim to examine the knowledge structure with co-word analysis where we study the patterns of co-occurence of words or phrases (concepts) in specific sets of database records, in order to identify research activities within a scientific area. Research activities in this field as demonstrated by co-word structure, and relations between different research topics, will be visualized through thematic maps. We wish to identify the principal themes and relations among them.

2 MATERIALS AND METHODS

We used the data retrieved from the three Web of Science Citation Indexes – SCI (Science Citation Index Expanded), SSCI (Social Science Citation Index), and A&HCI (Arts & Humanities Citation Index) accessed via WOS Core Collection (Thomson Reuters), as well as the data from CAB Abstracts database (CAB International) which is a principal international database for applied life sciences in relation to agriculture, environment, veterinary sciences, food science and nutrition.

In order to follow research topics we monitored different subject concepts, such as key words (descriptors), title words and classification codes. For the purposes of configuration and assessment of experimental data we prepared several operational databases in order to create and visualize different networks. In WOS we employed words from article titles, as well KeyWords+. These keywords are “index terms created by Thomson Reuters from significant, frequently occurring words in the titles of an article's cited references”. Based on WOS classification, we additionally analyzed the scatter of content across different subject areas (WOS categories). In CAB database, we used subject headings (descriptors) and CABIcodes. Both codes and descriptors are based on proprietary subject indexing of records in this database. CABIcodes are classification codes which define the broader subject scope of articles. Every record has at least one CABI code. Usually, there are more.

To delineate the scope of the field of nanoscience and nanotechnology we used the union of complex queries (Warris, 2004; Porter et al., 2008; Maghrebi et al., 2011) which defined the selection of relevant database records. These search methodologies were described in detail in our previous work (Stopar et al., 2016). Since important agro-nano applications are related to pesticides, our analysis mainly focused on this aspect (“nano-pesticide”). In addition, we combined the above search query (i.e. delineation of the field nanoscience) with concepts which apply to pesticides in a general sense, such as pesticid*, insecticid*, herbicid*, fungicid* and acaricid*. In case of CAB Abstracts, the share of those nano-related records which also relate to pesticides amounts to some 14 %. In case of WOS, this share is only 0.4 %. Data was retrieved at the end of 2014.

Evaluation of data was conducted with the use of a bibliometric tool Bibexcel (Persson, 2010). Integral part of this tool is an algorithm which performs the stemming of words. In our experiment, such words were used to identify co-occurrence of article-title terms. With the process of stemming, inflected or derived words were reduced to their word stem or root form (e.g. nanoparticles/nonoparticl; determination/determin; detection/detect; pesticides/pesticid; application/ applic).

Co-word analysis was used as a technique for the identification of relations and connections between various topics through the frequency of terms. It is presumed that such co-words analysis displays research activities within a scientific field. Visualization was prepared with the program Pajek, which is a program package for analysis and visualization of large networks (Mrvar and Batagelj, 2016). This software provides a possibility to display (visualize) networks and groups. It can elucidate important "knots" and individual points (vectors). It also reveals links between the points. The position on a picture and the strength of links show relations among the items. Images were prepared in vector EPS format (Encapsulated PostScript). GSview was used for this purpose.

3 RESULTS AND DISCUSSION

3.1 WOS Core Collection (SCI, SSCI, AHCI) - KeyWords+ and title words

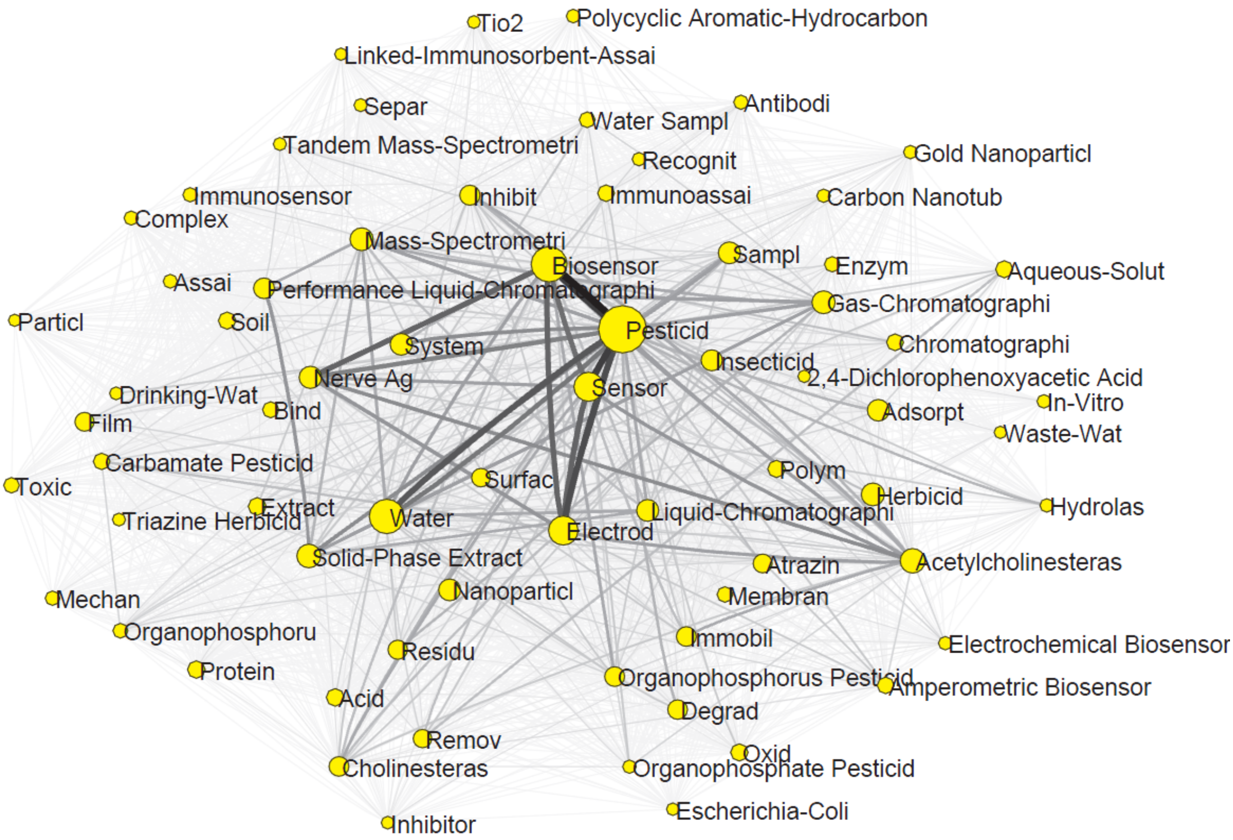
First part of the experiment presents the data based on WOS. The methodology described in the Methods section retrieved 3994 records.

Analysis of the scatter of content across different WOS categories shows that the records have been indexed with 207 different WOS categories. Some categories occur with negligible frequency. In terms of content the categories cover areas of analytical chemistry, electrochemistry, biochemistry, biophysics, biotechnology, as well as areas relating to environmental science, food technology etc. About 36 % (1441) of records are mapped to WOS category *Chemistry, Analytical*. The category *Nanoscience & Nanotechnology* has been assigned to less than 8 % of records (305).

The highest number of records was found in the journal *Biosensors & Bioelectronics*, followed by chemistry-related journals such as *Analytica Chimica Acta*, *Talanta*, *Analytical Chemistry*, *Sensors and Actuators B-Chemical*, *Journal of Agricultural and Food Chemistry*, *Journal of Chromatography A* etc.

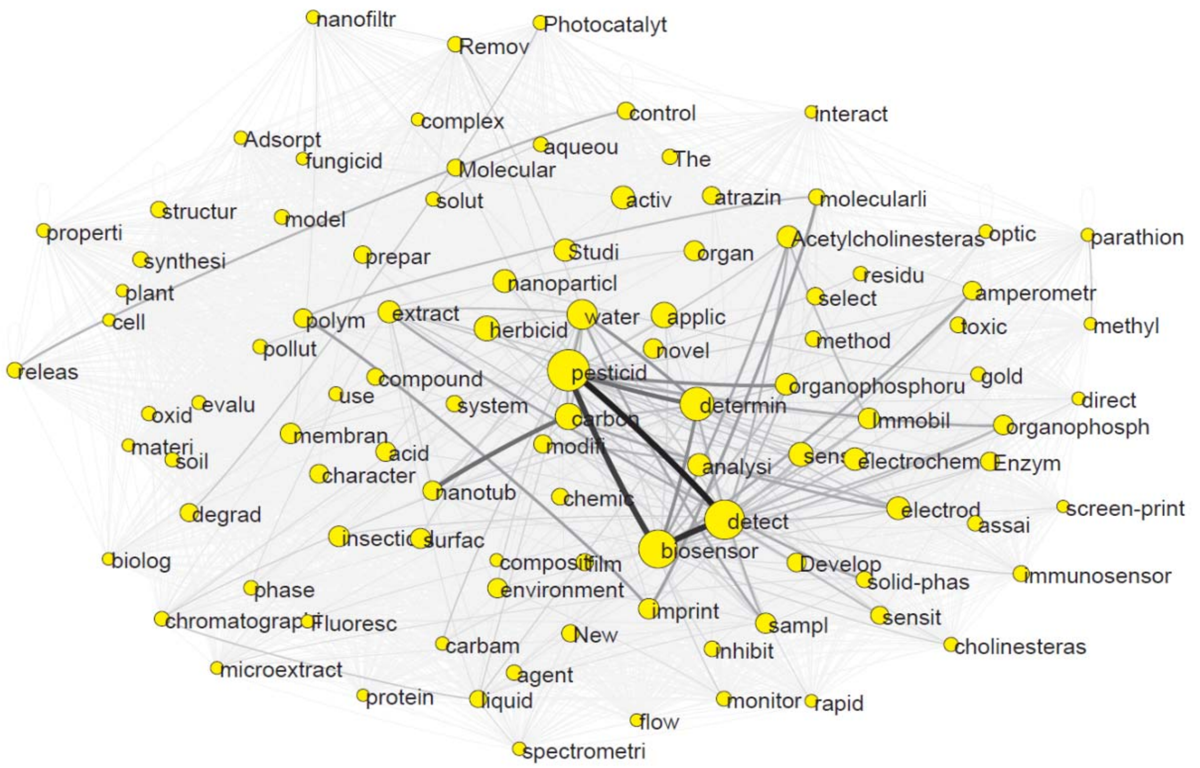
This sample of data was further assessed with co-word analysis. We used word-roots from article titles and KeyWords+. Figure 2 presents network of 70 KeyWords+ which occur with the highest frequency. In Figure 3, network of 100 most frequent title words is shown. As explained in Method section, word-roots have been used in both cases: we mapped related concepts to the same root in order to reduce the number of seemingly different concepts which, however, denote the same meaning.

The words related to the detection of pesticides, along with detection of biosensors, occur most frequently as is evident from circle size and ties between the words.



Legend:
circles: KeyWords+ / circle size: number of records / labels: the names of the most frequent KeyWords+ / lines: ties between pairs of KeyWords+

Figure 2: The network of the 70 KeyWords+ (word-roots) with the highest occurrence (WOS; sample: nano_pesticides)



Legend:
circles: words from article titles / circle size: number of records / labels: the most frequent words / lines: ties between words

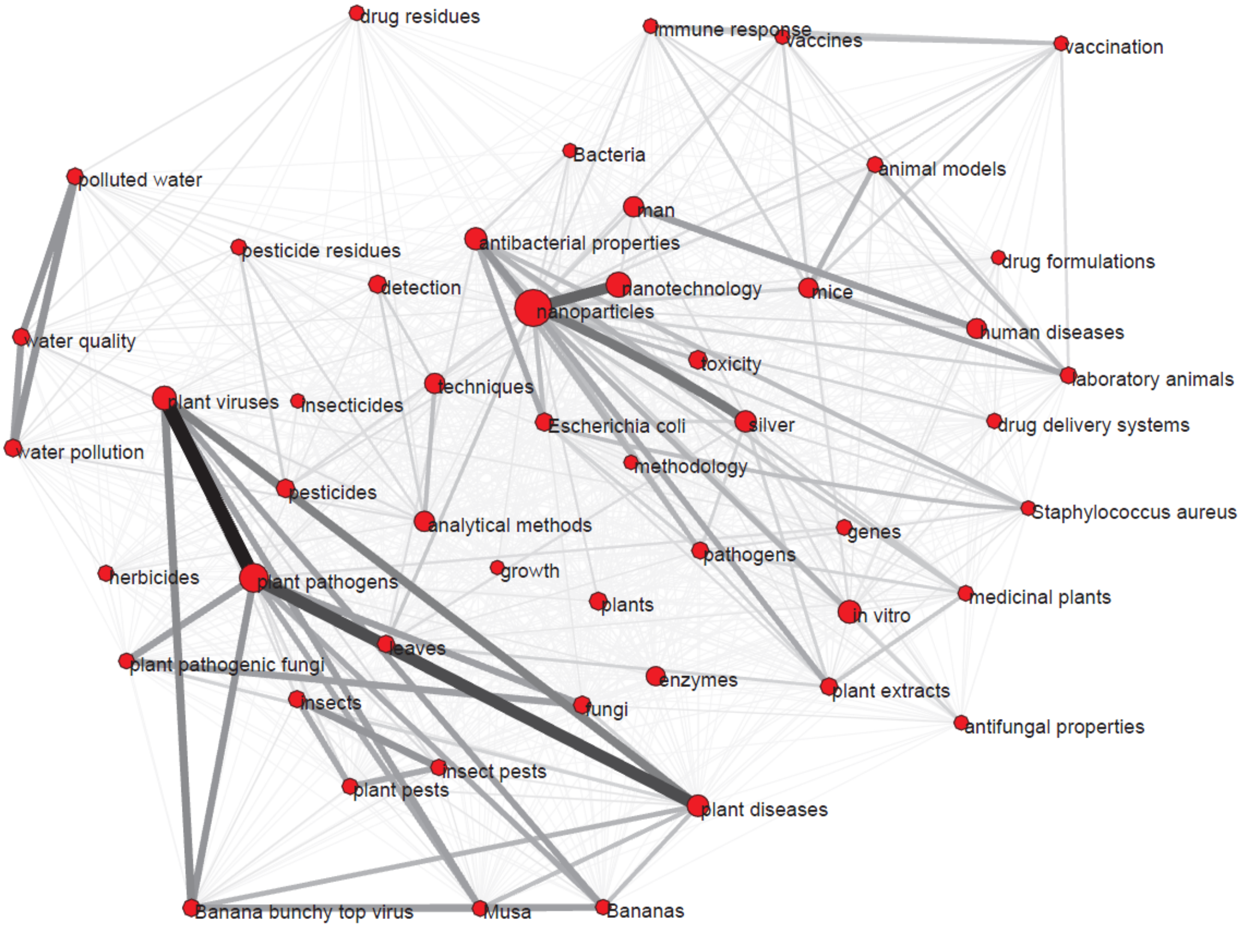
Figure 3: Network of the 100 words (word-roots) from article titles with the highest occurence (WOS; sample: nano_pesticides)

Figures 2 and 3 also indicate several other directions of research, for example, controlled release of pesticides, monitoring, degradation, detection of residues (e.g. herbicide, atrazine, triazine), nanoimprinting techniques (e.g. polym - imprint), studies on a molecular level, etc.

In the above case we employed the terms from the titles which are characterized by natural language. The terms in such context have a meaning only in relation to one another. At this point we wish to emphasize the importance of the specialists in the identification of relevant terms and detection of the topic in question. Thus, any similar results will strongly depend on terminology employed.

3.2 CAB Abstracts - descriptors and CABI codes

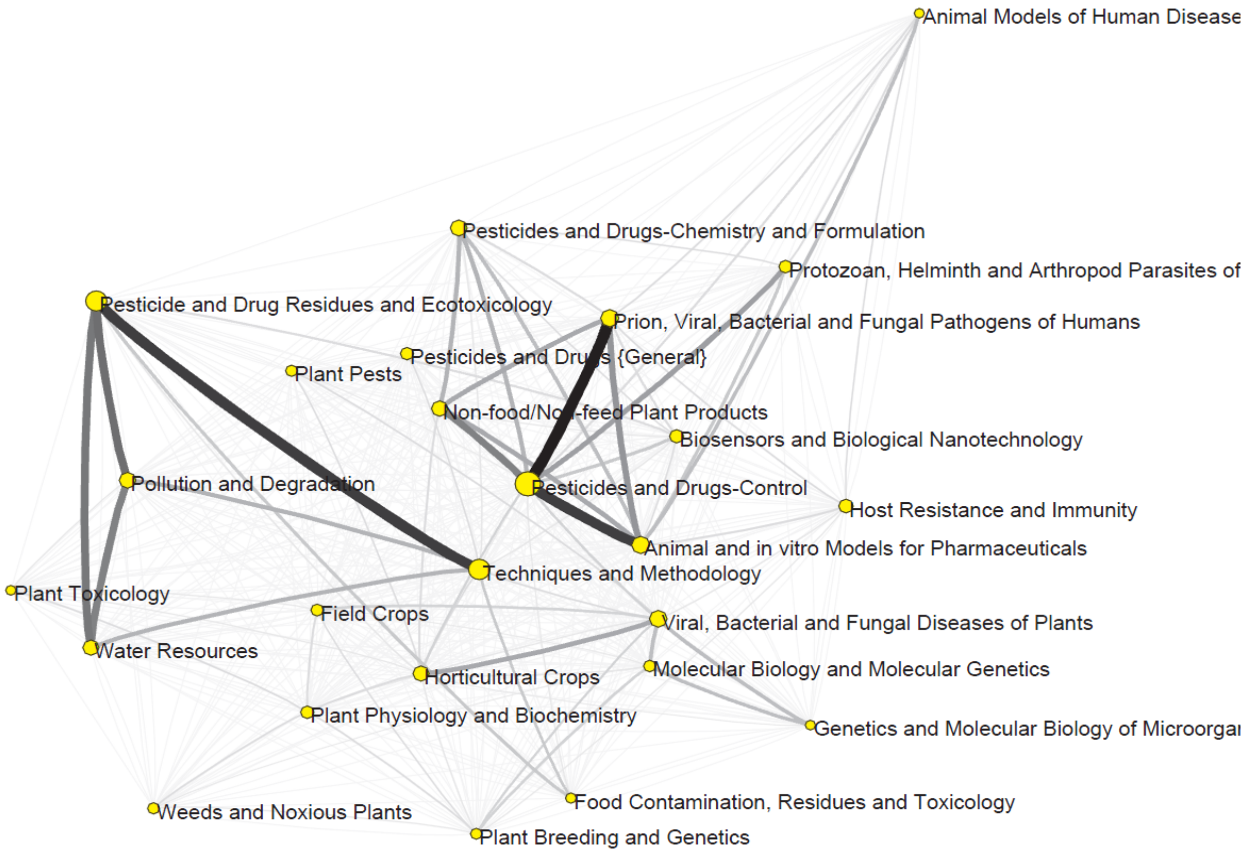
The second part of the experiment was based on CAB Abstracts. Data from this database has already been used for various bibliometric assessments (e.g. Bartol in Hočevar, 2011).



Legend:
circles: CAB descriptors / circle size: number of records / labels: names of the most frequent CAB descriptors / lines: ties between pairs of CAB descriptors

Figure 4: CAB descriptors (subject headings) with the highest occurrence (CAB Abstracts; sample: nano_pesticides)

The analysis of records related to the use of pesticides (sample: nano_pesticides; CABI codes and descriptors; Figures 4 and 5) indicates several important directions in the network. These directions are especially expressed in the topics of pollution and environmental studies, as well as topics related to human health and experimental animals (in relation to the models of animal examination). In Figure 5 the strongest links are detected between CABI codes *Pesticides and Drugs-Control* and *Prion, Viral, Bacterial and Fungal Pathogens of Humans*, as well as *Animal and in vitro Models for Pharmaceuticals.* There also exists a specific “nano CABI code” *Biosensors and Biological Nanotechnology* which shows connections with pesticides.



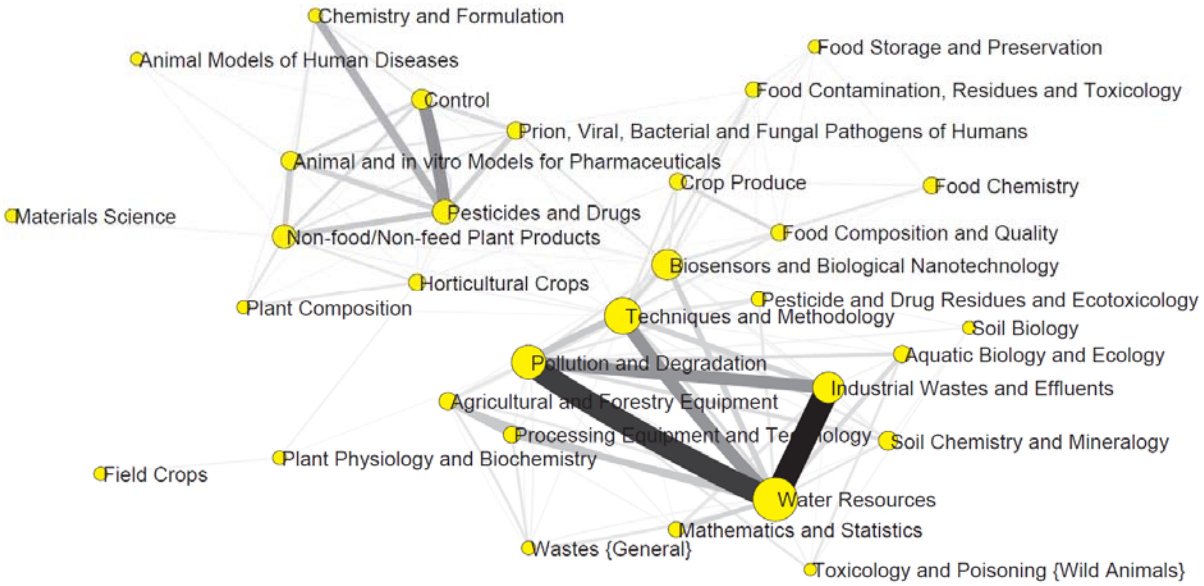
Legend:

circles: CABI codes / circle size: number of records / labels: the scope of the most frequent CABI codes / lines: ties between pairs of CABI codes

Figure 5: CABIcodes with the highest frequencies (CAB Abstracts; sample: nano_pesticides)

At the end, we present an additional analysis which is not directly related to the two above pesticide-based CAB models. CAB Abstracts database is dedicated to applied life sciences in relation to agriculture, environment, veterinary, food and nutrition so we also wished to examine the presence of nanoscience in a broader context - not just as applicable to only the more narrow aspect of pesticides. In this sense, we present results of co-word analysis of CABI codes which investigates the context of nanoscience more generally (Figure 6).

The results are based on the occurrence of word root nano* in article titles (publication year 2012). Figure shows CABI codes with the highest occurrence.



Legend:
circles: CABI codes / circle size: number of records / labels: the scope of the most frequent CABI codes / lines: ties between pairs of CABI codes

Figure 6: Network of the CABI codes (CAB Abstracts; search query: nano*.ti and 2012.yr)

We can observe that environmental issues are represented the most frequently. This is evident from the circle size. The strongest links can be found between the codes *Water Resources* and *Pollution Degradation* and *Industrial Wastes and Effluents*. More strongly expressed are also the ties between codes *Pesticides and Drugs* and *Control* or between codes *Techniques and Methodology* and *Water Resources* or *Pollution and Degradation* and *Industrial Wastes and Effluents*. The central place in the network is occupied by nanosensors. This is represented by CABI code *Biosensors and Biological Nanotechnology* which is connected with pesticides, crop production, water resources, quality of food and pathogens. A couple of major groups are revealed in the network, such as:

- water resources, wastes, pollution;
- nutrition (quality, chemistry, toxicology, contamination, storage and preservation);
- pesticides, diseases, protection, models.

4 CONCLUSIONS

Identification of current as well as emerging topics is important. It serves to better understand the developments in scientific research. Co-word analysis presents a significant tool to this end. The topics and connections can be ascertained by an analysis of the co-occurrence of various keywords or phrases. The aim of our study was to analyze the knowledge structure in nanoscience. Analyzing specific terms (keywords, descriptors) in databases CAB and WOS we thus evaluated the connections between nanoscience and agriculture (nano-agro concepts).

Examination based on CAB database, which is predominantly an agricultural database, shows strong emphasis on environmental studies where an important part of research also focuses on pesticides. In the networks of CABI codes the prominent place is occupied by sensors. Research topics linking human health and experimental animals are also strongly present. WOS-based examination also detected strong presence of topics related to biosensors and pesticides. The importance of sensors has also been emphasized by some other authors (for example, Cozzens et al., 2013). Some other directions of research such as controlled release, degradation, monitoring, detection of residues, studies at the molecular level, are also noticeable.

Bibliographic databases offer a large quantity of "organized" information, however, from the "raw" bibliographic data alone it is difficult to draw final conclusions on the connections and the flow of knowledge. Bibliometric mapping of science and subsequent visualization can still show important relations of selected elements and present the data in a more comprehensible way which makes it easier to understand and interpret what is possibly important.

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