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Assessment of the scientific basis of interdisciplinary, applied research Application of bibliometric methods in Nutrition and Food Research

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Abstract

We present the results of a study to assess crucial aspects and the strength of the scientific basis of a typically interdisciplinary, applied field: Nutrition and Food Research. Our approach is based on an advanced bibliometric analysis with novel elements to assess the influence and dissemination of research results and to measure interdisciplinarity. In order to adjust the contrast with 'single-disciplinary' research assessment, we represent application-oriented research by an interdisciplinary research profile that with a clear distinction between basic and applied research. Application of our approach to support an international audit of the Nutrition and Food Research Institute showed that advanced bibliometric analysis allows assessment beyond conventional academic standards. An important policy-relevant implication, strongly supported by the audit committee, is that realignment of an applied research institute toward a stronger market-orientation should not be at the expense of basic research. Not only is basic research the cradle of future applications, it acts also directly as an institutional visiting card for customers to show scientific thoroughness.

A novel element is a disciplinary breakdown of knowledge dissemination by a research institute based on a field-specific analysis of all publications citing the work of the institute. It reveals the mutual boosting of applied and basic research. Particularly, the analysis of publications citing applied work can be regarded as a novel indicator for potential users of knowledge and with that, new markets. In this context, it is important to compare actors (e.g. countries, institutes) involved in citing publications with those involved in the institute's international co-operation. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Evaluation of applied research; Bibliometric analysis; Knowledge dissemination; Interdisciplinary research

1. Introduction: bibliometric methods in research assessment

1.1. Main objectives of this study

This study focuses on the assessment of crucial aspects of the *scientific basis* of a typically interdisciplinary field: Nutrition and Food Research.

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Our approach is based on advanced bibliometric methods. To be as concrete as possible, and to put the work in a direct policy-relevant context, we apply our approach on the institutional level. Subject of our investigation is the Nutrition and Food Research Institute of The Netherlands Organisation for Applied Scientific Research (TNO). This institute is one of the major food science and technology institutes in Europe. The institute's mission statement is to link basic research to industrial application in the areas of foods, medicine and agro/fine-chemicals, in relation to health, safety, quality, and product and process innovation. Therefore, notwithstanding the typical applied orientation of the institute, an assessment of the *scientific basis of the institute's R&D* was considered as a matter of crucial importance and a major element in the evaluation of the institute by an International Audit Committee. Our study was primarily aimed at supporting this committee. We think that this practical and policy-relevant context enabled us to develop our approach more generally as a strategic method towards integration of evaluation in RTD (research, technology, development) policy making.

The main objectives of this study are the following. We want to show that bibliometric methods are not only applicable in basic sciences, but also in the applied fields of science, and particularly in an interdisciplinary environment. Next, there are four major interrelated policy-relevant goals. First, a breakdown of application-oriented research in both its more basic as well as its more applied components ('research profile'), with a performance assessment of these components separately. Here we show empirically the role of basic science in an interdisciplinary, applied field. Second, we show that not only a large application-oriented institute as a whole, but also its major divisions can be assessed successfully with our method. This means that the method may indeed provide crucial support in peer review or audit procedures. Third, we want to demonstrate clearly the differences in research impact for different modalities of co-operation. Fourth, the analysis of publications citing applied work leads to a novel indicator for identifying potential users of knowledge and, with that, new markets.

The time period covered is 1990–1996, an updating for the period 1996–2000 is in preparation. The study is based on an advanced bibliometric analysis (van

Raan, 1996) of scientific articles published in journals processed for the Science Citation Index (SCI) and related indexes, and containing at least one address from the institute. On the basis of the annual research reports of the institute, we conclude that international journals covered by the SCI play an important role in the dissemination of research results in this highly interdisciplinary research. Thus, our study adequately covers the publication output—as far as oriented toward international presentation of scientific results—in the field of Nutrition and Food Research.

1.2. Major characteristics of the institute

For The Netherlands, the food and nutrition industry and services sector is one of the most important economical sources of national prosperity (Engelsman and van Raan, 1993; Tijssen et al., 1996). Thus, research and development in this sector and related areas has a high priority in Dutch national science and technology policy. Our target institute plays a central role in this national nutrition and food R&D. The institute was founded in 1932 in Utrecht as part of The Netherlands Organisation for Applied Scientific Research (TNO). Initially, research was focused on Analytical Chemistry of food and food constituents, specialising on vitamin research and dietary deficiency diseases which was at that time a major research field at Utrecht University (Christiaan Eykman, discovery of vitamin B, battle against beriberi, Nobel Prize, 1929). Later the research was broadened with Microbiology, Food Technology and Toxicology.

Now the institute focuses on nutrition and health, quality and safety of food products and processes, and innovation in functionality and technology. Particularly, quality perception of food by the customer is a focal theme within the food and beverage industries. The institute's R&D reflect the importance of the above main subjects. Core activities are:

- integrated chain management in the food industry, aiming at product and process innovation;
- monitoring quality of food composition;
- functionality of food and feed constituents, particularly proteins and carbohydrates;
- gene technology for crop improvement;
- packaging of food, particularly taste, shelf-life, and safety;

- properties and safety of human and veterinary drugs;
- environmental occupational conditions in agro/fine-chemical and food industries;
- safety and quality of traditional and novel foods, non-food products such as cosmetics, base materials and chemicals;
- food consumption and digestion physiology in relation to health.

The institute aims at strengthening and renewal of these core competence by focusing at about 25 programs ('technologies'), grouped in a number of major divisions such as: Food Technology and Biotechnology, Analytical Methods, Human and Animal Nutrition, Toxicology, Microbiology and Quality Management. The institute acts as a World Health Organisation (WHO) Collaborating Centre for the Safety of Biotechnology, a WHO Collaborating Centre for Nutrition, and as a WHO Collaborating Centre for Occupational Health.

The institute operates on a turnover of about US\$ 65 million (1998), a quarter being financed by the government. The government support (decreasing from 30 to 25%) is particularly focused at stimulating 'breakthrough' projects aiming at new products. Another quarter of the turnover is from abroad, including the European Commission (e.g. projects within EC Framework Programs). The institute is developing a 'dual strategy': reinforcing its market-orientation, particularly outside The Netherlands, and at the same time improving its scientific position. Market growth is expected in the fine-chemical and pharmaceutical sector, the food sector being rather stable. Strengthening the links with major research centres, particularly outstanding university institutes, is seen as a most important element in the improvement of the institute's scientific position. Close linkages with universities are regarded as very important in maintaining a high research quality level and as a source for recruitment. Therefore, the institute closely co-operates with universities in The Netherlands, particularly in the fields of agriculture, phyto-technology, and veterinary research. Seven (1999) senior staff members hold 'extra-ordinary' (i.e. part-time) chairs at universities. This also enables young researchers to combine their work at the institute with completing a Ph.D.

The above mentioned 'dual strategy' should improve both the institute's patent as well as its publication position. The total staff of the institute has been around 560 in recent years but is now increasing rapidly up to about 700 (1999). One-third of the staff are academics. In the recent years of the period covered by this study (until 1996, an updating is in preparation) the institute published about 250 scientific articles and about 700 reports to customers annually. About 150 (of the 250) scientific articles, i.e. about 60%, is published in journals covered by the SCI. In agreement with the institute's researchers opinion, this 'SCI-covered' part will generally provide a reliable representation of the scientific basis of the performed R&D.

Quality assessment is conducted along two main lines: international audits required by the Institute's Umbrella Organisation (TNO) and the Royal Netherlands Academy of Sciences (KNAW), and internal assessments by annual 'technology position papers'. As discussed above, our study was designed for and primarily aimed at supporting the international audit procedure.

1.3. Bibliometric indicators and quality of scientific research

In a variety of studies bibliometric data have been used to assess research performance. This is particularly the case for the natural and life (medical, biological) sciences (Narin, 1976; Martin and Irvine, 1983; Moed et al., 1985; van Raan, 1993, 1996). The application of bibliometric methods in the assessment of scientific research is based on the following assumptions. Scientific progress is achieved by researchers with local, national, but primarily international characteristics who study research topics building on the work of other scientists ('knowledge accumulation model', Price, 1963). In this way, researchers work essentially in an international environment and keep each other informed of their research results. These results need to be published—otherwise they 'do not exist'—and thus they are submitted to a continuous evaluation by professional colleagues ('the peer judgement system', Merton, 1972).

By using references in their publications, researchers show how they have built on previous work. Criticisms of sociologists of science on citation

analysis are based on the ‘reference behaviour’ of scientists, which would be so unstructured that one cannot base quality assessment on citation data (see for instance Cozzens, 1989, and Luukkonen, 1997). We disagree with these sociological arguments on the basis of simple statistical considerations. Citation analysis does not concern one publication but a (very) large set of publications. The citations ‘received’ are ‘given’ by many different authors having different ‘reference behaviours’. We discussed these statistical arguments in detail (see Peters et al., 1995, and van Raan, 1998b). Moreover, our long-standing experience in bibliometric analysis yielded a clear empirical prove that analyses of scientific performance can be carried out very well on the basis of scientific literature, which is, as it were, an image of (at least substantial parts of) scientific activity. The number of publications of a group is considered to be an indication of its scientific production. The number of times this body of literature is cited world-wide, can be regarded as a measure of the impact or the international visibility of the research.

Scientific journals, particularly in the natural and the life sciences, play an essential role in the communication between colleagues. As far as journals are concerned, we distinguish ‘core’ journals, i.e. leading international journals with a well-functioning referee-system, and ‘peripheral’ journals, i.e. less important journals, often more national in scope. The SCI, produced by the Institute for Scientific Information (ISI) in Philadelphia, claims to cover the core, i.e. most important journals in the natural and life sciences. The SCI contains about 3500 journals. As a general rule, SCI coverage of scientific journals is less adequate in the more technical or applied fields of science than in basic natural and life science disciplines. Moreover, conference proceedings and reports play an important role in the communication of research results in application- and problem-oriented research. Such proceedings often appear in conference books, and, consequently, they are not covered by the SCI. Nevertheless, our study convincingly shows that the scientific journal is an important communication medium for Nutrition and Food Research and that the SCI covers the major part of the journals. Furthermore, an increasing number of conference proceedings is published in regular journals (often as ‘special issues’). In as far as these journals are covered

by the SCI, the proceedings concerned will also be covered.

Citation-based indicators point to *one specific, but important quality aspect* referred to as international influence or *impact*. These bibliometric indicators represent the response of the international research community to the published work of a group, expressed in references in scientific literature. We stress that bibliometric indicators are not meant to replace the evaluation of experts. But they can offer crucial information about research performance that can be seen as complementary to peer opinion. This is particularly important, as peer review also has serious drawbacks (Horrobin, 1990; Wennerås and Wold, 1997). Therefore, it is our firm belief that the *combination* of advanced bibliometric methods—such as presented in this study—and peer review is the best approach to evaluate research performance (van Raan, 1996). In this study, we try to convince the reader that advanced bibliometric methods indeed has a much larger potential than often suggested by opponents (van Raan, 1998a) or by poorly informed evaluation-experts such as in the recent COSEPUP (1999) report.

In several earlier studies comparisons have been drawn between bibliometric results and the judgement of experts on the perceived quality of research teams. The two approaches appear to correspond with each other in a predominantly significantly positive way (Martin and Irvine, 1983; Nederhof, 1988; Nederhof and van Raan, 1987, 1989). None of these studies, however, allowed a sufficiently detailed ‘fine tuning’ of the different types of bibliometric indicators and the different aspects of peer review. Recent empirical work now presents ample evidence of correlation between a set of different bibliometric indicators and peer review criteria. Remarkable differences in correlation for the various indicators have been found, but particularly the indicators normalised to *field-specific* characteristics show a strongly positive correlation with peer review criteria (Rinia et al., 1998). These findings reinforce the applicability and ‘acceptability’ of bibliometric indicators. Even if a correlation is significant, it is not perfect. Thus, there is a good chance that a judgement on the basis of bibliometric results does not correspond with the opinion of colleagues. But it is certainly not sure that the *peers* are right. Empirical work shows that peer opinions can differ considerably.

Bibliometric results, notably at the aggregation level of a department, must be interpreted with background-knowledge. This background-knowledge may refer to specific circumstances (e.g. publication ‘habits’) within a department, but also to the international characteristics of the research field in which the department is active. Bibliometric methods focus specifically on the research task and, more in particular, on the contribution to the development of knowledge at the international research front. This implies that activities relating to other aspects remain unconsidered. We mention for instance teaching related to supervision of Ph.D. students, dissemination of scientific knowledge at the national level, typical institutional policy-related activities (such as reports to the European Commission), or typical ‘R&D’ and technological work, as reflected in patents. Work is in progress to study the influence of typical food and nutrition trade journals.

1.4. Data collection

In this study, we collected all publications of the Nutrition and Food Research Institute as far as these publications are covered by the SCI of the Institute for Scientific Information (ISI). We applied automated data searching routines to our CWTS bibliometric data-system. This CWTS data-system contains all scientific articles, published from 1980 up till now (monthly updates) in journals processed by the Institute for Scientific Information (ISI) for the SCI, the Social Science Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI). Moreover, it contains information of all scientific publications which have cited any of these articles during the period from 1980 up till now (again monthly updates). Furthermore, the data-system includes citation data on all journals processed for the SCI, SSCI or A&HCI. A detailed description of this data-system is given in Moed et al. (1995). A special part of the data-system concerns the publications with at least one corporate address from The Netherlands.

We emphasise that a number of specially designed, crucial ‘added values’ characterise our data-system. For instance, ‘cleaning’ of bibliographic data, corrected author names and addresses, unified hierarchical structures of addresses (by using our CWTS scientific addresses database), automated procedures

such as corrections for self- and ‘in house’ citations, choice of aggregation level, article-type related characteristics, world-wide and European Union impact standards as reference values. Next to these data-specific ‘added values’ there are many special software-routines to calculate a wide variety of indicators (each having the possibility of different options). Furthermore, each assessment project conducted by us includes a thorough verification of publication-data by representatives of the institute(s) involved and/or by using the institutional annual research reports. All additions and corrections are cumulatively included in our data-system, in a separate ‘verified’ sub-system parallel to the original data. This procedure illustrates our systematic and continuous efforts to improve the bibliometric data-system. With help of our data-system, we created a ‘verified’ set of 1395 publications from our target institute for a 10-year period, 1987–1996.

As far as the delineation of the field concerns, Nutrition and Food Research, we always have in the case of assessing selected institutes the following simple rule: the fields is, what the institute does. Evidently, typical interdisciplinary research such as on nutrition and food problems (e.g. food contamination) is based on many different fields (e.g. Toxicology), each having their own ‘community’. In order to compare the research performance of an interdisciplinary institute in a specific research field with an international reference value for that specific field (‘world-wide’ or European average), it is essential to have a clear definition of that specific field. Such a ‘field definition’ depends on the way scientific publications are classified.

In general, we deal with two main types of classifications based on international databases.

1. Publications are ‘labelled’ with one or more *classification codes* indicating fields as defined by a ‘fixed’ thesaurus of codes given by a specialised database of a specific field for instance, Physics Abstracts, Chemical Abstracts, or MEDLINE for the medical research fields.
2. Publications are classified only on the basis of the *journal* in which it appears. This type of classification is used in the Science Citation Index, the ‘ISI journal categories’.

In our research profile analysis we will use these journal categories as a first and, as we shall see,

reasonable approximation to define fields that form the palette of which Nutrition and Food Research is composed.

The structure of this paper is as follows. In the next chapter, we present the results of our research assessment analysis for the institute *together* with a (short) methodological discussion of the bibliometric indicators applied in this study. Essentially, our indicators relate to different aspects of research performance: *publication output*, *impact*, and *interdisciplinarity*. Particularly, important impact indicators are those measures in which the impact of the research institute is compared to a *world-wide reference value*. We introduce a novel approach to analyse and measure interdisciplinarity. In Chapter 3, we present the results of two selected research programs within the institute in order to discuss the method on an aggregation level directly below the institutional. Again, we focus on aspects of interdisciplinary research. Finally, a first validation and a general discussion are given in Chapter 4.

2. Research performance and interdisciplinarity at the institutional level

2.1. Basic indicators of research performance: output and impact

In this section, we present a general introduction to our bibliometric method. To make this presentation more effective, we apply our methodology directly to the institute. Scientific output is defined as the number of articles of the institute concerned, as far as covered by the SCI, SSCI, or the A&HCI. This indicator (symbol P) can be determined on an annual base or for the whole period 1990–1996. As an ‘article’ we consider the publication-types ‘normal articles’ (including

proceedings papers published in journals), ‘letters’, ‘notes’, and ‘reviews’ (but not meeting abstracts, obituaries, corrections, editorials, etc.).

Table 1 gives the number of papers published (P), as well as the number of citations (C). We measure output and impact ‘cumulatively’ during a fixed time period of 4 years, based on *all* publication and citation data related to this period. A trend analysis for the whole period (1990–1996) is established by using ‘roof tiles’: successively overlapping 4-year periods. Thus, 1990–1993 is the first ‘block’, followed by 1991–1994, 1992–1995, and 1993–1996. For papers published in the first year of a block—for instance, 1993 in block 1993–1996—citations are counted during the period 1993–1996, for 1994 papers citations in 1994–1996, for 1995 papers citations in 1995–1996. For papers published in 1996 only the impact received in 1996 is taken into account, as far as this 4-year block concerns. Clearly, in this type of trend analysis the most recent publication and citation data available can be included. In an updating of the study, the trend analysis is extended by adding the blocks 1994–1997, 1995–1998, 1996–1999, and (partly) 1997–2000. There is ample empirical evidence that in the natural and life sciences—basic as well as applied—the average ‘peak’ in the number of citations is in the third or fourth year after publication (van Raan and van Leeuwen, 1995). Therefore, 4-year ‘roof-tiles’ are appropriate for impact assessment.

Next, the average number of citations per publication (CPP) (calculated by dividing the total P of a specific block of years by the total C of that block) is presented. CPPex is the same indicator without self-citations. A self-citation is defined as a citation given in a publication of which at least one author (either first author or co-author) is also an author of the cited paper. This is a rather ‘broad’ definition of self-citation. Other options are possible.

Table 1
Trends of the institute’s basic indicators, 1990–1996

Year block	P	C	CPP	CPPex	% Pnc	JCSm	FCSm	CPP/JCSm	CPP/FCSm	JCSm/FCSm	% Scits
1990–1993	599	1710	2.85	1.79	37.4	2.63	2.51	1.08	1.14	1.05	37.2
1991–1994	638	1850	2.90	1.82	37.2	2.82	2.71	1.03	1.07	1.04	37.2
1992–1995	627	2056	3.28	2.19	34.8	3.11	3.01	1.06	1.09	1.03	33.3
1993–1996	637	2178	3.42	2.23	34.2	3.14	2.86	1.09	1.20 ^a	1.10	34.8

^a Indicates that the ratio is significantly above 1.0, confidence level 95%. For the applied statistical test, see Moed et al. (1995).

The percentage of self-citations, % Scits, as well as and the percentage of not-cited papers, % Pnc, are given in the table.

An important indicator is the average citation rate of *all* papers (world-wide) in the journals in which the institute has published (JCSm, the mean Journal Citation Score of the institute's 'journal set'). Thus, this indicator JCSm defines a world-wide reference level for the citation rate of the institute (CPP). Comparing these two indicators, we are able to assess whether the measured impact is *above* or *below* world average. A novel and unique aspect of our comparison with this world-wide reference value is the following. We take into account the *type* of paper as well as the specific *years* in which the papers were published (Moed et al., 1995). This means that the roof-tile counting procedure is also applied to JCSm. This is important, as the average impact of journals may have considerable annual fluctuations (Moed and van Leeuwen, 1995, 1996).

We notice that comparison of the institute's citation rate (CPP) with the average citation rate of its journal set (JCSm) ignores the level of these journals. For instance, if the institute publishes in *prestigious* (high impact) journals and another institute in rather mediocre journals, the citation rate of articles published by both groups may be equal relative to the average citation rate of their respective journal sets. But the first group evidently performs better than the second. A second disadvantage of JCSm is the following. If, for instance, the institute publishes frequently in general, multidisciplinary journals of high prestige such as *Nature*, then it is very well possible that Nutrition and Food Research papers will have a lower impact as compared to the average of *Nature* which is dominated by bio-molecular research, a field characterised by high absolute citation numbers. In such a case, JCSm is not a fair international reference level for nutrition research.

Thus, we developed a second world average reference level. It is based on the citation rate of all papers published in *all* journals of the field(s) in which the institute is active, and not only of just the journals in which the researchers publish their papers. Here we use the definition of fields based on a classification of scientific journals into *categories* developed by ISI. Although this classification is far from perfect, it is at present the only classification available

to us in terms of an automated procedure within our bibliometric data-system. Currently, we are developing field-definitions based on clusters of co-word related publications-clusters (Noyons et al., 1999). In calculating this field-based world average FCSm, we use the same procedure as the one we applied in the calculation of JCSm. Often an institute is active in more than one field. In such cases, we calculate a weighted average value, the weights being determined by the total number of papers published by the institute in each field. For instance, if an institute publishes in food science and technology journals *and* in Toxicology journals, then the FCSm of this institute will be based on both field averages. Thus, indicator FCSm represents a *world average* in a specific (combination of) field(s). About 80% of all SCI-covered papers are authored by scientists from the United States, Western Europe, Japan, Canada, and Australia. Therefore, our 'world average' is dominated by the Western world.

Furthermore, we calculate the ratio of CPP to the above discussed world averages, JCSm and FCSm, respectively. If CPP/JCSm is above 1.0, the impact of the institute's papers exceeds the journal-based world average. Similarly, if CPP/FCSm is above 1.0, then the institute's work is cited more frequently than the field-based world average. Table 1 shows that this is the case for our target institute.

The ratio JCSm/FCSm is also an interesting indicator. Is it above 1.0, then the mean citation score of the institute's journal set exceeds the mean citation score of all papers published in the field(s) to which the journals belong (which again is the case for our target institute).

Thus, we conclude that the institute's overall research impact is well above world average particularly in the recent period. But this impact is not as high as in the late eighties (we found for the period 1987–1990 a CPP/FCSm value of 1.47). Furthermore, the institute publishes in journals with, generally, above-average impact. The performance 'dip' in the beginning of the nineties was explained by the institute's researchers in a remarkable way: for policy reasons the institute had to move in the late eighties from a more basic-oriented research program to a more application-oriented one. And this, according to the scientists, was at the expense of the institute's international scientific impact.

2.2. Interdisciplinarity of institutional research

2.2.1. Interdisciplinary profile of the institute's research

Another important part of our bibliometric analysis is the *breakdown* of the institute's output (publications) into research fields (defined in terms of sets of journals). First, the breakdown as such gives a useful impression of all fields involved in the research scope

or 'profile' of the institute. This can be seen as an indicator of interdisciplinarity. Next, we determined the *impact* of the articles in these different fields, so that it becomes immediately visible in what fields within the interdisciplinary research profile the institute has a high (or lower) performance.

The institute's research profile for the entire period (1990–1996) is presented in Fig. 1. It is a striking illustration of what interdisciplinarity means: the

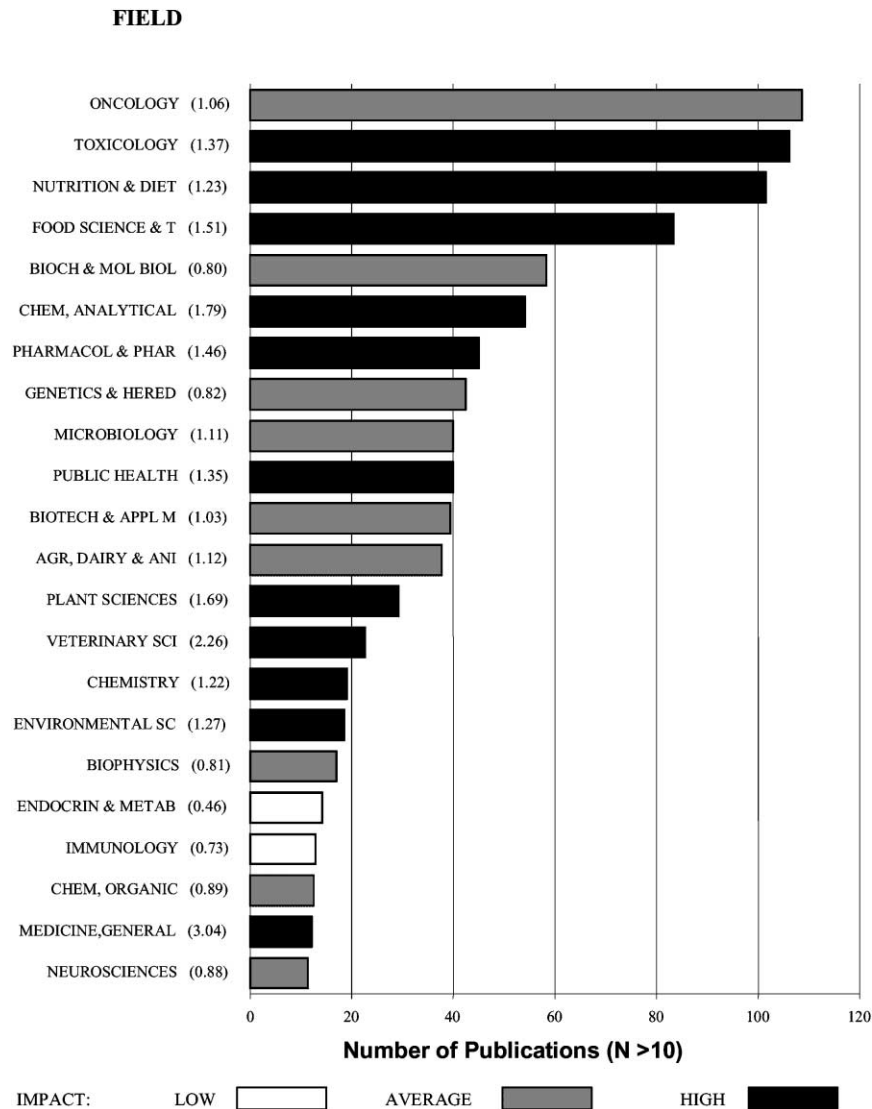


Fig. 1. Interdisciplinary research profile of the institute (output and impact per field), 1990–1996. CPP/FCSm values are given after the name of the field. Low impact: CPP/FCSm < 0.8; high: CPP/FCSm > 1.2 (fields with less than 10 papers are not displayed).

institute's research relates to many fields of science. In the figure we display the fields in which the institute published more than 10 papers, the number of these fields is around 20. As can be expected, Nutrition and Dietary Research and Food Science and Technology, but even more pronounced (in publication numbers) Oncology and Toxicology, and further Biochemistry and Molecular Biology and Analytical Chemistry are the institute's major research fields, in terms of output. Except for Oncology and Biochemistry and Molecular Biology, the impact of the institute's research in these fields (indicator values are given behind the names of the fields in the figure) is well above the international average, particularly for Food Science and Technology, the institute's 'core business'. Next to these fields, in terms of output, we find Pharmacology and Pharmaceuticals (impact well above world average), Genetics and Heredity, Microbiology (impact for both fields around world average), Public Health Research (impact well above world average), Biotechnology and Applied Microbiology, Agriculture, Dairy and Animal Science (impact for both fields around world average), Plant Sciences and Veterinary Sciences (impact for these both fields are above to far above world average). Smaller fields (in terms of output) are Chemistry (General), Environmental Research, Biophysics, Endocrinology and Metabolism, Immunology (impact for the latter two fields is below world average), Organic Chemistry, Medicine (General), Neurosciences.

Next, we compare the institute's profiles (now limited to the major fields) of an earlier period (1990–1993) and a recent period (1993–1996) in Fig. 2. We observe several striking changes. A decrease of impact can be observed for Biochemistry and Molecular Biology, Biotechnology and Applied Microbiology, and for Genetics and Heredity, from around to below world average, and for Pharmacology and Pharmaceuticals from above to around world average. The institute improved its impact in Nutrition and Dietary Research and in Oncology, from around to above world average. Food Science and Technology as well as Analytical Chemistry keep their high impact, but show a decrease of publication activity. This is an interesting and important finding. Food Science and Technology is the 'core business' of the institute, and it is crucial to maintain a high quality scientific basis. Analytical Chemistry is also crucial to the institute, as it has the ambition to develop its analytical skills and

to market this expertise. A thorough scientific basis is necessary for this development and our findings are indications that the institute succeeds in this strategy. While retaining impact, the decrease in output in both fields is significant. This observation may very well reflect a certain priority shift to more applications.

Our bibliometric analysis clearly illustrates the broad, interdisciplinary scope as to what the institute sees as 'food and nutrition science'. The above finding also illustrates the difficulty to 'define' an interdisciplinary field such as food and nutrition research on a general basis and to 'prescribe' beforehand how such a field should look like. Evidently, it is better to analyse what an institute itself sees as 'food and nutrition research'.

2.2.2. *Interdisciplinary profile of the institute's 'knowledge users'*

A novel element in this study is a first step in the analysis of knowledge dissemination based on a field-specific breakdown of all publications *citing* the work of the institute.

This analysis provides first indications of the 'users' of the institute's scientific knowledge, particularly in terms of research fields. In Fig. 3, we combine the institute's research profile (Fig. 1) with the profile of the citing publications. Quite remarkable is the observation that not the 'core business' fields (Nutrition and Dietary Research, Food Science and Technology) are the main sources of citing publications, but Biochemistry and Molecular Biology, Oncology, Toxicology and Pharmacology and Pharmaceuticals.

We also measured the impact of the citing publications, thus providing information about the scientific 'status' of the citing work: is the institute cited by the better, or by mediocre work? Fig. 3 provides a clear answer. Most of citing publications in the various fields are characterised by high impact.

The results of a further empirical analysis of interdisciplinarity are given in Table 2 and Fig. 4. In Table 2, we present for the largest 10 fields of the institute's research profile (see Fig. 1) for each field ('cited fields', columns) the distribution of citing publications over fields ('citing fields', rows). The period of analysis is 1990–1996 for both the *cited* (institute's publications as well as the *citing* publications). The number of publications can be a non-integer as publications may be classified in more than one field.

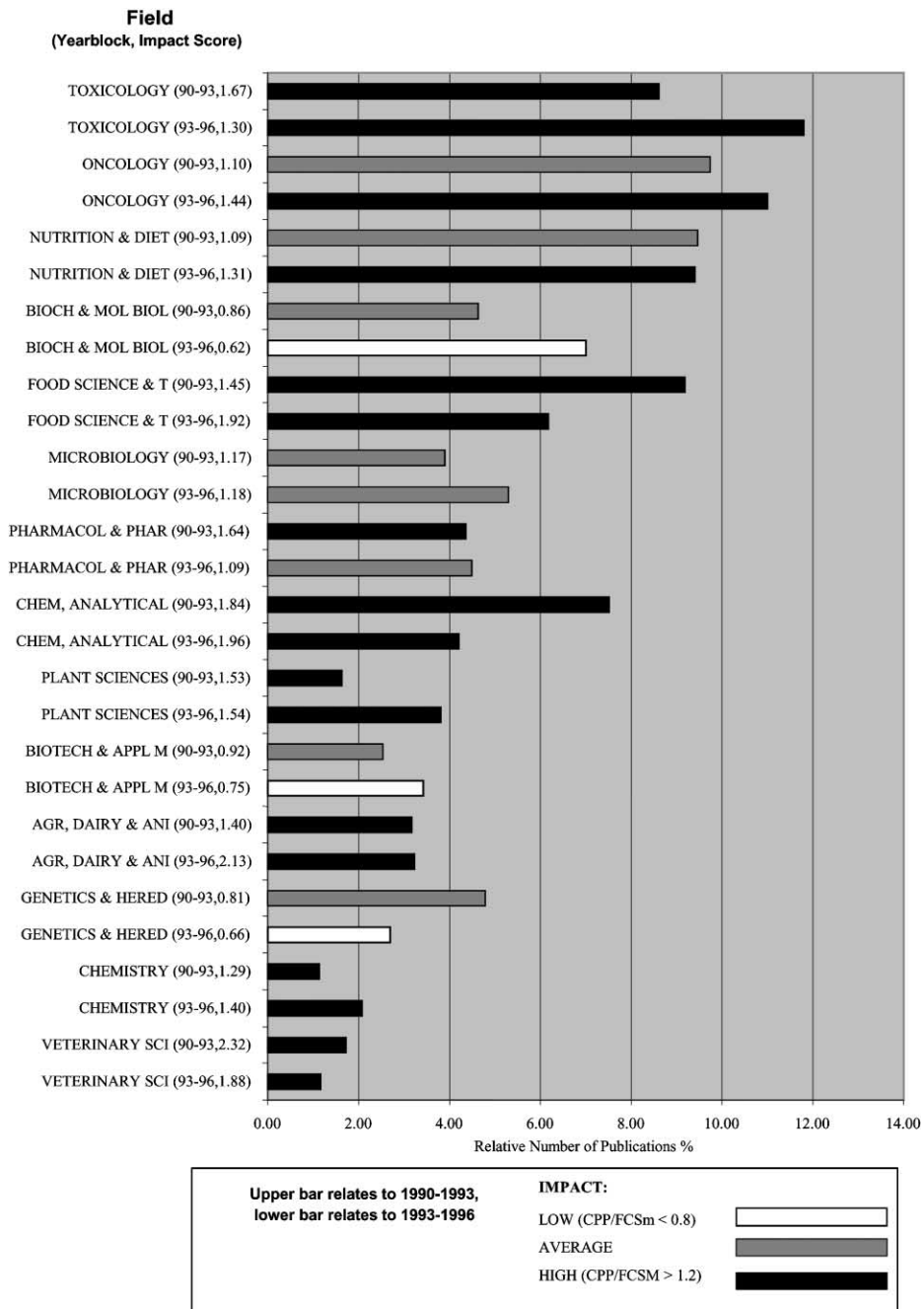


Fig. 2. Recent development of the institute's interdisciplinary research profile. Comparison of 1993–1996 with 1990–1993, relative output (percentage of total number of publications) and impact per field.

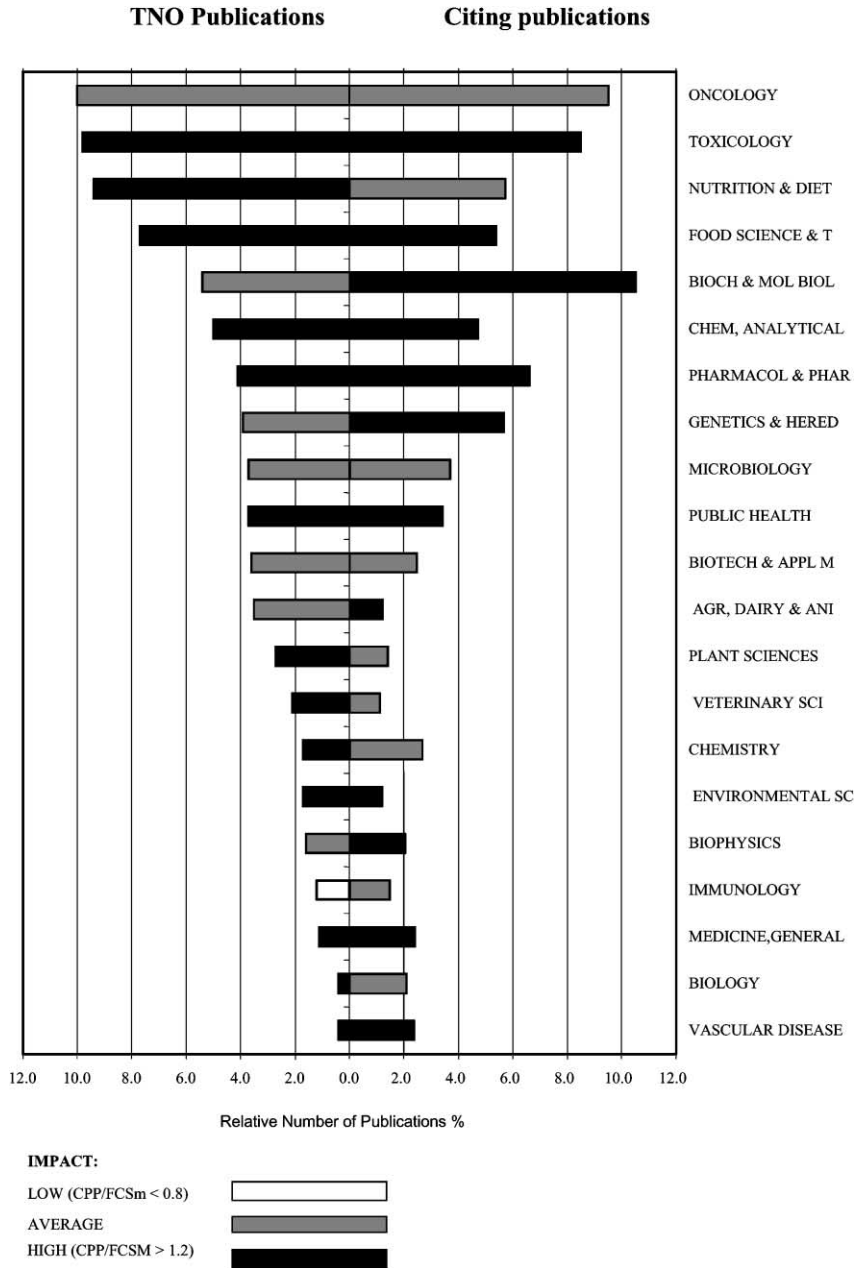


Fig. 3. Interdisciplinary research profile of the institute in comparison with the profile of the citing publications, 1990–1996.

For instance, in the first column we find the number of publications citing from different fields the Biochemistry and Molecular Biology publications of the institute. We see that the institute’s publications are cited most frequently by publications from the same field

(Biochemistry and Molecular Biology), as can be expected, but also frequently from medical fields such as Genetics and Heredity, Oncology, and Hematology. The data in the table clearly show the influence of the institute’s research in specific fields on other fields.

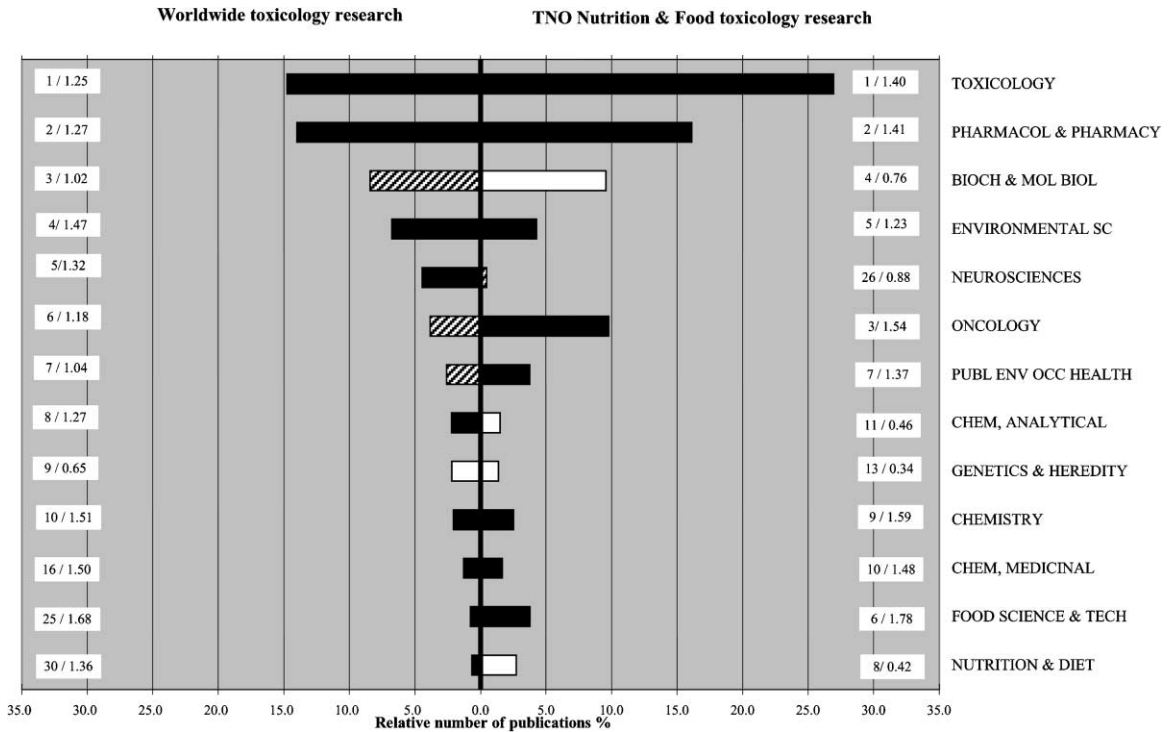


Fig. 4. Interdisciplinary influence of world-wide toxicology research compared with that of the institute's toxicology research, 1990–1996.

In Fig. 4, we present a further elaboration of this analysis. The influence of toxicology world-wide (i.e. all toxicology papers in the given period of time) on other fields (indicated on the vertical axis of the figure as 'citing fields') is compared with the influence of toxicology research of the institute on the same fields (based on about 400 citing publications in the given period of time). The numbers within the white rectangle at the extreme left and right side of the figure indicate the ranking (in terms of number of publications) of the 'citing' fields and—behind the slash—the impact of the citing publications in the field concerned. Because of the very large amount of cited and citing publications 'world-wide', we used for Fig. 4, a sub-set of the data used in Table 2: the institute's publications ('cited publications') concern the time period 1990–1992 and the citing publications the period 1990–1996.

This comparison nicely illustrates the general interdisciplinary relations of toxicology vis-à-vis the interdisciplinary relations of toxicology research within the setting of a food and nutrition research institute.

For instance, the institute's toxicological work is used (in terms of cited) significantly more by Oncology researchers and significantly less by neuroscience researchers than the world-wide average for toxicology. As to be expected, the institute's toxicology work is also significantly more than average cited by Food Science and Technology as well as by Nutrition and Dietetics researchers. In other words, we empirically demonstrate that the concept of interdisciplinarity has significant institutional characteristics.

2.3. International scientific co-operation and impact

We also analysed the institute's performance in relation to scientific co-operation. This analysis is based on the affiliation addresses of the publications. We first identified papers authored by scientists with just the address of the institute. To these papers we assigned the co-operation type: *no co-operation*. With respect to the remaining papers we established

Table 3

Relation between institutional output, impact and type of co-operation, most recent period: 1993–1996

Type of collab	<i>P</i>	<i>C</i>	CPP	CPPex	% Pnc	JCSm	FCSm	CPP/JCSm	CPP/FCSm	JCSm/FCSm	% Scits
Institute	182	565	3.10	2.07	36.8	2.79	2.51	1.11	1.24	1.11	33.5
Nat. collab.	309	1098	3.55	2.28	31.1	3.46	3.33	1.03	1.07	1.04	35.8
Int. collab.	151	526	3.48	2.28	37.1	2.87	2.33	1.22	1.50	1.23	34.6

whether authors participated from other institutes in the same country (*national co-operation*), or from institutes outside the country of the institute (*international co-operation*). If a paper has three or more addresses, e.g. co-operation with another institute in the same country as well as with an institute outside the country, it is marked as ‘international’. The purpose of this indicator is to measure the amount of collaborative output and to determine how the impact of papers is related to the different co-operation types.

The results are shown in Table 3 for the period 1993–1996. We find that the institute gains the highest impact (far above world average) with publications in international co-operation. This finding is quite general (Narin and Withlow, 1990). A somewhat lower impact but still considerably above world average is found for publications originating from the institute ‘alone’. Remarkably, those publications that are written in national co-operation, show the (relatively) lowest impact (but still around world average).

From the addresses of the institute’s co-publications we derived a country-specific co-operation profile. The first 10 countries are UK, US, Germany, Belgium, Switzerland, France, Italy, Spain, Finland, and Sweden. Generally, the pattern of international co-operation is dominated by two main factors: first, the scientifically largest countries (most of the ‘G7’ countries) have a large share, and second, neighbour-countries play an important role. This pattern is clearly visible, but there are some striking features. First of all, the position of Finland is much more prominent than one would expect from the above general ‘rules’. Second, Switzerland shows up as an important partner. The Finnish position reflects a characteristic of TNO, the Institute’s Umbrella Organisation. TNO served in the 1980s as an example for a new Finnish applied research organisation, VTT. The strong emphasis of TNO on food research was followed by VTT and since then the two organisations

kept close contacts in this field of applied research. The relatively strong co-operation with Switzerland is due to co-operation with several food and nutrition companies.

The above figures concern the institute as a whole. Co-operation with R&D institutes abroad not necessarily focuses on the core fields, Nutrition and Food Research. Therefore, it is important to analyse international co-operation on a lower aggregation level and see what specific programs of the institute dominate international co-operation, and what programs are more nationally oriented. This will be discussed in Section 3.3.

In Fig. 5, we compare the country-specific *co-operation* profile (‘co-workers in the knowledge production’) with country-specific profile of the *citing publications* (‘users of the produced knowledge’). Discrepancies may suggest new possibilities for co-operation and, possibly, new markets. Those countries that frequently cite the institute’s work may be important as customers for the institute’s products and services. We observe that several countries are much more pronounced as ‘citing country’ than as ‘collaborating country’. This is particularly true for the US, France, Italy, Canada, Japan the former USSR, and Australia. This latter information could be interpreted in terms of possible new co-operation partner and/or markets.

Similar to the field-specific breakdown of citing publication to fields (Section 2.2.2 and Fig. 3) we also measured in this country-specific breakdown the impact of the citing publications. We notice the low impact of, among others, the Italian, Japanese and Russian (partly former USSR) citing publications. High impact citing papers are from the US, Germany, Australia, Sweden, Switzerland and Finland. Perhaps these high impact citing papers indicate countries where the institute has strong competitors, rather than possibilities for new markets.

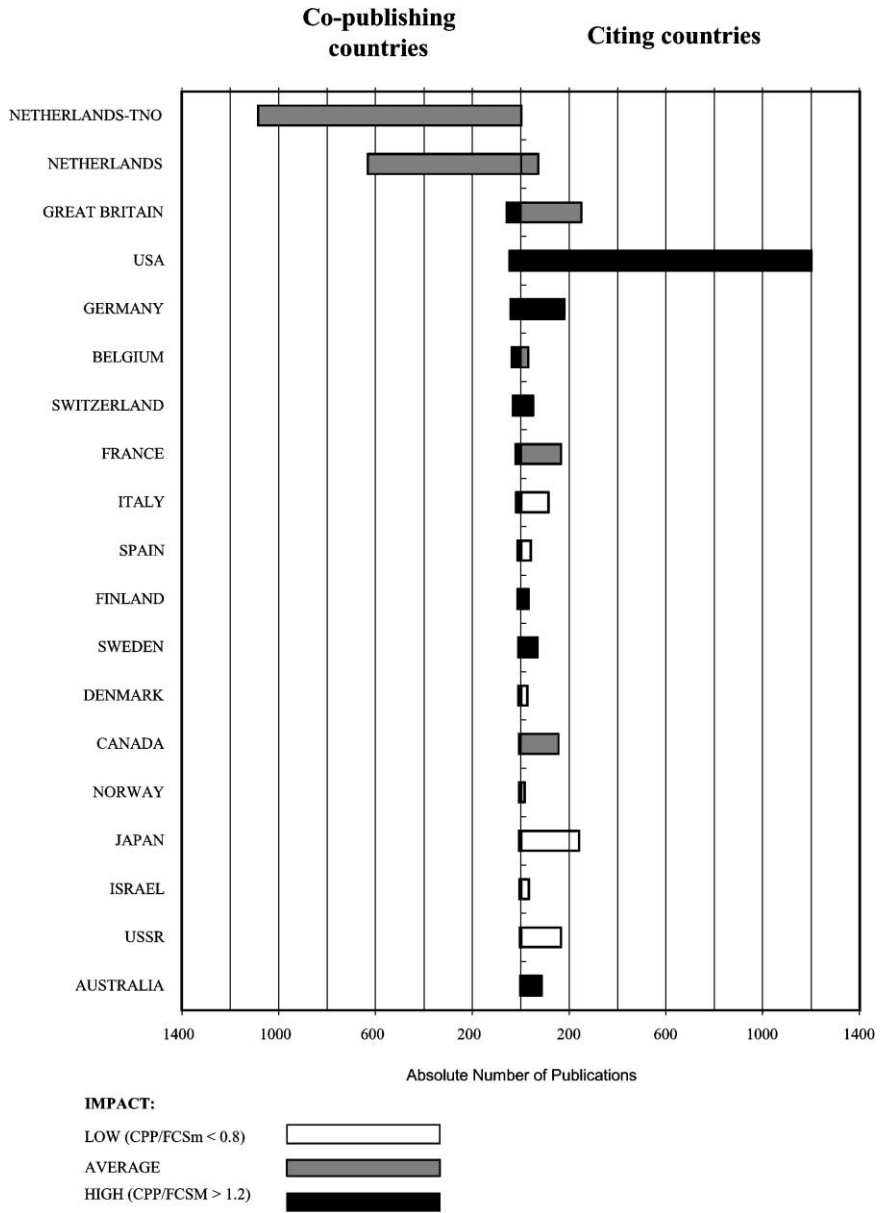


Fig. 5. Comparison of the output and impact of the international co-operation profile with the international citing profile, 1990–1996. Number and impact of publications in international co-operation, left side; number and impact of citing publications, by country, right side.

Table 4
Institutional programs

Food Safety and Quality
Information Technology
Food Epidemiology
Occupation and Chemistry
Non-Food Analysis
Bio-Analysis
Pharmacology
Food Analysis
Contaminants and Organic Analysis
Packaging Research
Plant Biotechnology
Agro Raw Materials
Proteins, Carbohydrates, and Enzyme Technology
Gene Technology
Bio-Process Technology and Biomonitoring
Food Technology
Animal Feed and Meat Technology
Food Physiology
General Toxicology
Target Organ Technology
Explanatory Toxicology
Environmental Toxicology
Nutritional Microbiology
Animal Feed Technology

3. Research performance and interdisciplinarity at the level of institutional programs

3.1. Basic indicators of research performance: output, impact, interdisciplinarity

As discussed in Chapter 1, the institute's research is conducted (during the time period covered by this study) in about 25 programs. They are listed in Table 4.

We choose for discussion two programs that are characteristic for a Nutrition and Food Research Institute: *Food Epidemiology* and *Explanatory Toxicology*. We calculated the basic bibliometric indicators presented in Chapter 2 for these two programs. The results are presented in Table 5 for the trend analysis 1990–1996. This approach supports the institutional research management to monitor the overall scientific performance in main programs. In the next section, the performance of each of these four programs is broken down into specific fields (basic as well as applied) according to the profile analysis as discussed in Section 2.2.1. First we present the results of the overall analysis.

For the Food Epidemiology program the trend analysis indicates a rather stable publication output. However, a clear *increase* of international research impact from an already high to a very high level is observed—CPP/FCSm is now far above world average—together with a strong improvement in the choice of journals (indicator JCSm/FCSm). Researchers have more or less stabilised this program in terms of size, but they successfully invested in quality.

The institute's research in the Explanatory Toxicology program shows a steady increase in publication numbers, but a quite dramatic decrease in impact from far above to just around world average. Journal choice is around average international level.

The above examples make clear that there are substantial differences in performance between the various institutional programs. For the institute's management and the researchers it is of vital importance to keep track of these developments in performance, particularly for the benefit of a healthy international

Table 5
Trends of the basic indicators for two institutional programs, 1990–1996

	<i>P</i>	<i>C</i>	CPP	CPPex	% Pnc	CPP/JCSm	CPP/FCSm	JCSm/FCSm	% Scits
Food Epidemiology									
1990–1993	68	220	3.24	2.22	47.1	1.39	1.46	1.05	31.4
1991–1994	65	246	3.78	2.88	30.8	1.39	1.60+	1.15	24.0
1992–1995	64	407	6.36	5.09	29.7	1.59	2.18+	1.37	19.9
1993–1996	62	421	6.79	5.21	25.8	1.29	2.44+	1.89	23.3
Explanatory Toxicology									
1990–1993	53	205	3.87	2.34	37.7	1.17	1.21	1.03	39.5
1991–1994	64	242	3.78	2.33	37.5	1.09	1.14	1.05	38.4
1992–1995	68	234	3.44	2.18	33.8	1.22	1.09	0.89	36.8
1993–1996	77	263	3.42	1.97	32.5	1.09	1.00	0.92	42.2

co-operation. For instance, in Explanatory Toxicology there is substantial co-operation with Belgium, France, UK and Japan. Decreasing scientific performance might, on the longer term, endanger further co-operation and possible markets. On the other hand, in Food Epidemiology the institute may focus on further collaboration with centres of excellence.

3.2. *Interdisciplinary science base of application-oriented programs*

The breakdown of the publications of each research program into fields, and the determination of the impact in these different fields, gives a comprehensive overview of all fields involved in the interdisciplinary research scope or ‘profile’ of a program. We here again focus the discussion to the two chosen programs. We present the research profiles of the period 1990–1996, see Fig. 6a and b. The research profiles of the institute’s programs provide a clear insight into the interdisciplinary ‘composition’ of these programs, i.e. the fields in which the researchers in a program are active as given by the journals used by the researchers for their publications.

We observe that in the institute’s Food Epidemiology program major research fields are Nutrition and Dietary Research, Public Health Research, Oncology, and Medicine (General). The performance in all these fields is (far) above world average (see CPP/FCSm values given in the figure behind the name of the field), as can be expected given the total impact of this program. From the 1993–1996 data (van Leeuwen and van Raan, 1998) we find that in the most recent years Oncology increased its share considerably in publication output in the Food Epidemiology program. It shows the growing scientific interest in the relation between food and cancer.

The institute’s program on Explanatory Toxicology is also dominated by Oncology, be it with impact around world average (see CPP/FCSm values), and Toxicology, with performance above world average. Smaller fields of activity are Genetics and Heredity (impact below world average) and Biochemistry and Molecular Biology, with impact above world average. In the recent period 1993–1996 the basic field for this program, Toxicology, increased its share in publication output, but the impact decreased to around world average.

The above discussion of these research profiles shows that it is possible to monitor the interdisciplinary ‘mix’ of institutional programs, particularly the ‘dominating’ fields and the research performance within these fields.

3.3. *Scientific co-operation within application-oriented programs*

In Section 2.2.2, we hypothesised that those countries with which the institute maintains a relatively strong collaborative relation in specific programs, are also the countries that are important as customers for the institute’s products and services. Therefore, it is important to analyse international co-operation on a lower aggregation level and to find out which programs of the institute dominate international co-operation, and which are more nationally oriented.

The programs chosen as an example for analysis on a departmental level are characterised by a considerable but not exceptionally high amount international co-publications. Whereas the institutional average is around 25%, for Food Epidemiology the number of publications in international co-operation is 17% and for Explanatory Toxicology it is around the institutional average, 24%. The first program is more nationally oriented. Given the high impact of the research in this program, the potential for international co-operation with foreign centres of excellence is higher. With an institutional average of about 50% for (intra-)national co-operation, the national co-publications amount to 65% in Food Epidemiology. Explanatory Toxicology is with 54% around institutional average. A further analysis of the institute’s programs shows that Gene Technology has the highest amount of international co-publications, 30%, and Occupation and Chemistry with the lowest, 7%. As often, we see that more socially oriented R&D (here: labour conditions) will be less internationally oriented than a typical ‘hard-science’ field such as genetic research.

Co-operation with other countries shows preference for specific programs. We mentioned in Section 2.2.2 the special position of Finland. Co-operation with this Nordic country is particularly focused on Food Epidemiology. Co-operation with neighbouring (and partly same language speaking) country Belgium

concerns mainly Gene Technology and Explanatory Toxicology, whereas the co-operation with our other neighbours, Germany, is strongest in Animal Feed and Meat Technology. Co-operation with the UK concerns a broader spectrum, but particularly Explanatory

Toxicology. Co-operation with Switzerland and the US focuses on General Toxicology. Specific interests are also found for co-operation with further countries: Spain, Israel, and Thailand on Food Epidemiology, Japan on Explanatory Toxicology.

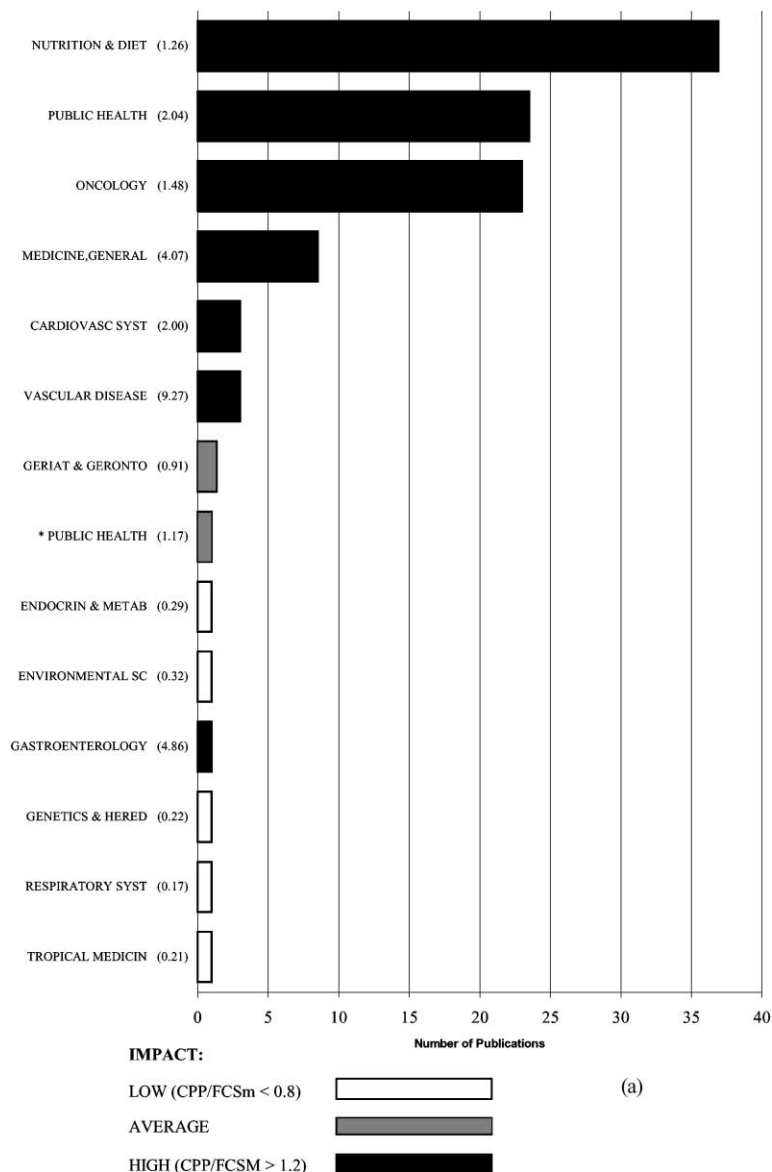


Fig. 6. (a) Research profile (output and impact per field), program on Food Epidemiology, 1990–1996. Impact is normalized to the field-based world average (CPP/FCSM); (sub)fields with less than two papers are not displayed. Upper-bar relates to publications in 1993–1996, lower-bar relates to publications in 1990–1993. On the x-axis the (fractional) number of publications is given. Dark-coloured bars indicate CPP/FCSM > 1.2; shaded bars indicate 0.8 < CPP/FCSM < 1.2; light-coloured bars indicate CPP/FCSM < 0.8. (b) Research profile (output and impact per field), program on Explanatory Toxicology, 1990–1996. Legend: see Fig. 6a.

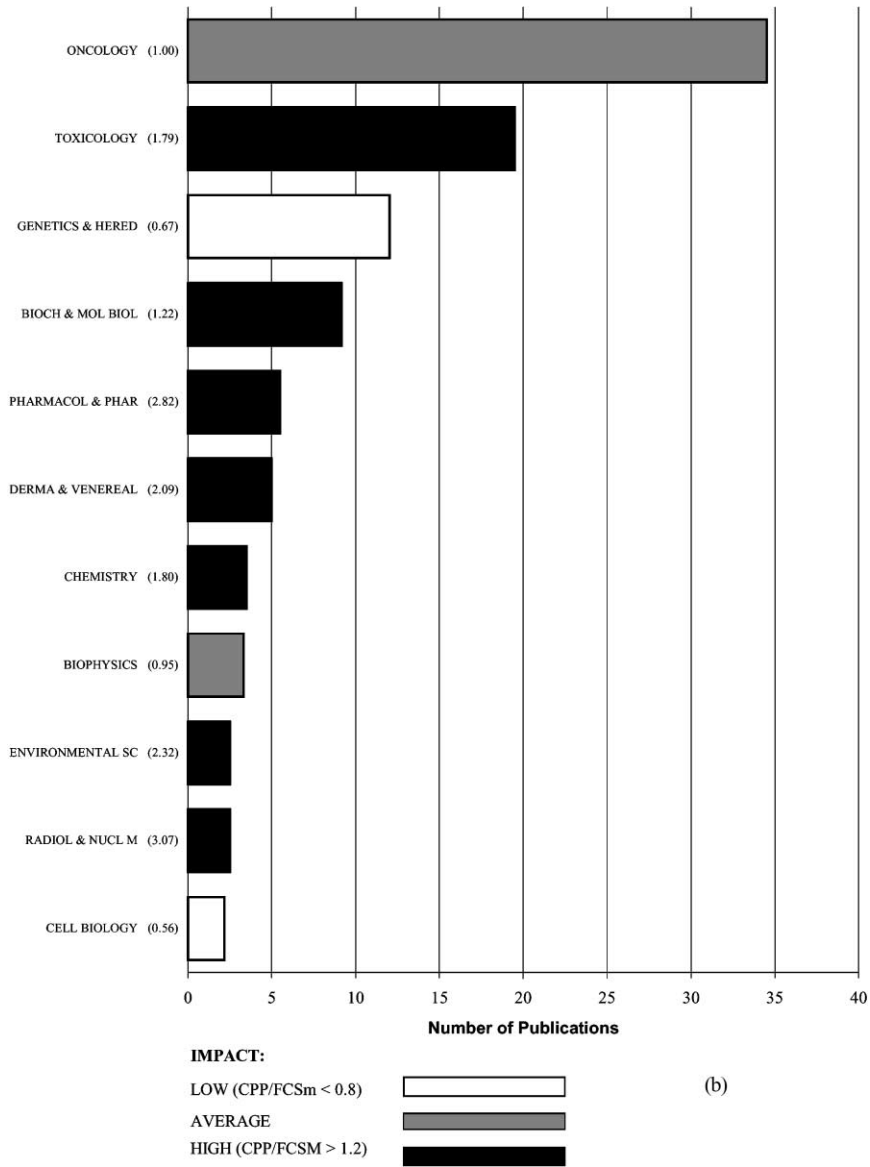


Fig. 6. (Continued).

4. Discussion of the results in the context of an international audit

4.1. Opinions within the institute and assessment by an international audit

We discussed the results of this study with division heads and senior staff involved in most of the

programs, in total about 10 prominent researchers. Although the institute is a typical application-oriented institute, there is an outspoken consensus about the importance of publishing articles in refereed, international scientific journals. In cases where research is better characterised as ‘development’ and mainly devoted to application of existing knowledge, the institute’s researchers agree that other media than

international journals, such as reports and trade journals, are the primary publication outlets. The interviewed scientists also stressed that presentation of results in international conferences is extremely important, particularly to keep pace with the rapid developments.

There is a strong agreement that peer review must remain the central part of any research evaluation procedure. But most of the scientists felt that a thorough bibliometric analysis such as conducted in this study, adds to the evaluation procedure important values that can hardly or not be provided by peers. Essential 'added values' are interviewed scientists *objectivity* and *new insights*, particularly in terms of (1) *trends* in impact, (2) *profiles* of the institute and its research programs, proving the outspoken interdisciplinary activities of the institute, and (3) *comparison* with other institutes or with international standards. Another important 'added value' provided by this analysis is insight into (4) *publication strategies* both on an individual as well as on the institutional level.

The institute's researchers argued that it is not always possible to publish the results of their work, due to strict confidentiality of certain projects. In such cases, bibliometric analysis is not applicable, and also peers will not be able to assess the performance. 'Judgement by users' will be prove of the quality of the work, but this will concern the applications, and not scientific value. So a problem may arise for the institute: how to make new knowledge, and thus scientific progress, on the basis of confidential projects? Somehow these client-bound experiences must find their way to contribute to the general scientific development of the field. A possibility is to lay down application-oriented new knowledge in patents, but most scientists did not consider patenting as a primary means of (applied) scientific 'communication'.

All division heads and senior staff agreed that the results of this bibliometric analysis are largely consistent with their opinions about the level of performance, and most particularly with the trends and even with the details as represented in the 'research profiles'. There were some discrepancies between the perceived quality of individual researchers and the 'citedness' of their papers. The interviewed scientists underlined the importance of the breakdown of the institute's papers into different types of co-operation and stressed the problem arising from the 'interpretation' of co-operative

publications. In a number of publications the institute appeared as one of the addresses (mostly not the first one), indicating a co-operation with another institute or university group (often the 'parent' University of Utrecht). Although, given the addresses, these publications are regarded formally as also an institute's paper, the interviewed scientists indicated several examples for which they regarded the contribution of the institute as restricted. If such papers would be highly cited, then it would certainly give the wrong impression to credit the institute with this performance.

In this work, we emphasised the operationalization of an institute's research profile. We conclude from discussions with the interviewed scientists that this focus is a good choice. It is clear that the typical interdisciplinary character of the institute makes the use of these profiles much more 'profitable' than in the case of, for example, astronomy research where the profiles are evidently dominated by one discipline (van Raan and van Leeuwen, 1995). Particularly, the comparison between profiles of earlier and of recent periods were considered as very informative. The interviewed scientists agreed that accurate 'fingerprints' of changes in research orientation are provided by these profiles and that the recent research policy history of the institute is reflected remarkably well. The institute's scientists explained the relative decline in performance by a *policy-induced* shift from a more *basic*-oriented toward a more *application*-oriented research program. The scientists feel that this policy decreased the research performance in terms of international impact or 'visibility'.

The indicator JCSm/FCSm gave rise to lively discussions about the role of journals in a specific (sub)field, and the choice of these journals. Quite outspoken was the statement that in some cases it is better to choose for 'sub-top' journals and to have a publication relatively rapidly published, than to start a lengthy 'struggle' to get your work published in a top-journal. It would cost too much additional time for relatively small improvements. Especially this situation is pertinent to American top-journals, particularly for European researchers.

The international audit committee was concerned about the institute's more longer-term research program, possibly signalled by of a slowing down of publication numbers. Although the committee appreciated the reinforcement of application-oriented

activities, they warned that further market-orientation should not lead to a decrease of incentives for basic research. This committee considered the bibliometric results as ‘characteristic data’ for the health of the scientific position of the institute as a whole and its different programs. Particularly, the CPP/FCSm indicator was considered as important. The audit committee took the view that the ‘scientific image’ of the institute is essential for its ‘market attractiveness’.

We conclude that our quantitative, bibliometric analysis reveals important research management and policy relevant aspects of scientific performance. It is an efficient tool to *monitor* and to *evaluate* the position of a research institute in international context. In this case, the institute uses our bibliometric performance assessment to prepare an international audit.

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