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DOCUMENTOS 132

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Mara Angélica Pedrochi
Thais da Silva Justino

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Embrapa Pecuária Sudeste
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Caixa Postal 339
Fone: (16) 3411- 5600
www.embrapa.br/pecuaria-sudeste
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Mara Angélica Pedrochi

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Maria Cristina Campanelli Brito

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Autores

Patricia Menezes Santos
Engenheira Agrônoma, pesquisadora da Embrapa Pecuária Sudeste, São Carlos, SP

Moacyr Bernardino Dias-Filho
Engenheiro Agrônomo, pesquisador da Embrapa Amazônia Oriental, Belém, PA

Juarez Campolina Machado
Engenheiro Agrônomo, pesquisador da Embrapa Gado de Leite, Juiz de Fora, MG

Frederico de Pina Matta
Engenheiro Agrônomo, pesquisador da Embrapa Pecuária Sudeste, São Carlos, SP

Allan Kardec Braga Ramos
Zootecnista, pesquisador da Embrapa Cerrados, Brasília, DF

Valeria Pacheco Batista Euclides
Engenheira Agrônoma, pesquisadora da Embrapa Gado de Corte, Campo Grande, MS

Amaury Burlamaqui Bendahan
Engenheiro Agrônomo, pesquisador da Embrapa Roraima, Boa Vista, RO

Naylor Bastiani Perez
Engenheiro Agrônomo, pesquisador da Embrapa Pecuária Sul, Bagé, RS

Ana Clara Rodrigues Cavalcante
Zootecnista, pesquisadora da Embrapa Caprinos e Ovinos, Sobral, CE

Mara Angelica Pedrochi
Bibliotecária, analista da Embrapa Pecuária Sudeste, São Carlos, SP

Thais Silva Justino
Bibliotecária, São Carlos, SP

Sumário

Introduction

Beef and milk production in Brazil is mainly pasture-based (ASSIS et al., 2005; ABIEC, 2018; FERRAZ; FELÍCIO, 2010). There is around 160 million ha of pasturelands in Brazil, which represents 45% of the agricultural area (IBGE, 2017). Sown pastures represent around 70% of the total pasture areas and are located mainly in the North, Southeast and Center-West regions of Brazil (IBGE, 2018).

Grass and forage research in Brazil has shifted focus along the years. Traditionally, grass and forage research focused mostly on topics related to forage and animal production. Currently, besides the search for increasing production to fulfill a growing worldwide animal protein demand, grass and forage research faces new challenges like land degradation, climate change, competing land use, environmental impacts, including natural resources utilization, deforestation, loss of biodiversity, fragmentation, and loss of habitats, reduction on 'labor force' in rural areas, sustainability, among others.

Indicators on science and technology reflect the central tendencies on scientific, technological and innovative activities from a country, institution or knowledge area. The development of specific indicators on science and technology on grass and forage science may be helpful for planning and evaluating activities of research groups and policy-makers alike. Based on specific indicators on science and technology it is possible to identify the main topics and grass and forage science research groups, and also verify if their activity is related to the main problems from the pasture-based animal production sector. This information may contribute to the more efficient use of research resources and to the progress of scientific advance on pasture-based animal production sustainability and competitiveness.

This report aimed to evaluated grass and forage research indexed by Web of Science, between 2005 and 2015, to support decisions from the Portfolio of Research on Grass and Forage Science of Embrapa. Specific indicators on science and technology on grass and forage science were analyzed. Tendencies on scientific and technological activities were evaluated for three main groups of research topics: specific topics traditionally investigated on grass and forage science; transversal and multidisciplinary topics traditionally investigated on grass and forage science; and new topics, which are related to new challenges that pasture-based animal production sector are currently facing.

1 Search strategy

The search strategy was based on recommendations from Lopes (2002), who considers the relationship between specialists on library and information science and specialists on the specific scientific domain. The general theme of the search was discussed on meetings between specialists on library and information science and specialists on grass and forage science for a better understanding of the critical questions that should be approached during the search. After that, keywords were selected from a technical report elaborated by the Portfolio of Research on Grass and Forage Science of Embrapa (EUCLIDES et al., 2015), complemented by information from a thesaurus (ALLEN et al., 2011) and specialists on grass and forage science.

Keywords were combined and search expressions were elaborated to recover publications related to grass and forage science (Table 1). Whenever necessary, new arguments were included on the search expressions to avoid the recovery of publications that were not related to the primary purpose of the search. These arguments were elaborated based on the analysis of the search results and determined the exclusion of publications related to specific words or specific journals. On most

searches we looked for the specified keywords in the fields “title”, “abstract”, “authors keywords”, “Keywords Plus®” (keywords determined by database)” (Table 1; #1 to 10, #16, and #19 to 23), but whenever keywords represented general terms broadly used to describe material and methods of experiments, we decided to restrict our search to the field “title” (Table 1; #11 to #15, #17 and #18). This way, the absolute number of publications recovered by each search expression should not be compared with each other and does not imply on differences of relevance between specific topics; just the tendencies between years should be analyzed.

A general expression was determined and used to both recover publications on grass and forage science and to be combined with other expressions as a filter (#1). Arguments #1.2 and #1.4 were combined with the main expression #1.1 to avoid the recovery of publications not related to grass and forage science.

Two expressions were determined to identify publications on cultivated (#2) and natural (#3) pastures, and three expressions were elaborated to identify publications related to legumes (#4), tropical grasses (#5), and temperate and subtropical grasses (#6).

Besides that, expressions were elaborated to recover publications related to specific topics traditionally investigated on grass and forage science (“Traditional topics”: pre-breeding (#7), plant breeding (#8), grazing management (#10), pasture restoration in Brazilian biomes (#11), forage quality and feed supplementation (#12), forage conservation (#13), production systems(#14)), transversal and multidisciplinary topics traditionally investigated in agricultural crops, including pastures (“transversal topics”: seed technology (#15), stress (#16), soil science (#17), water use and conservation (#18)), and emergent topics which are related to new challenges that pasture-based-animal production sector are facing nowadays (“emergent topics”: automation (#19), climate changes (#20), agroclimatic zoning (#21), integrated systems (#22), modeling (#23)). We also addressed the question “which problems breeding programs are focusing on?”, considering aspects such as global climate changes, genetic diversification, intensification of production systems, sustainability of production systems, forage quality, feed supplementation and ideotypes of forage plants (#9).

Table 1. Search expression used to recover publications from Web of Science database, between 2005 and 2015.

Identification	Search expression
#1 – General expression	#1.1 - TS[(1)]=(Pasture* OR grassland* OR "grazing land*" OR "pasture land*" OR Panicum* OR Brachiaria* OR Andropogon* OR Pennisetum* OR Cynodon* OR Cenchrus* OR Digitaria* OR "Setaria italica*" OR "setaria sphacelata*" OR Hemarthria* OR Chloris* OR Paspalum* OR Stylosanthes* OR Arachis* OR Cajanus* OR Leucaena* OR calopogonium* OR lespedeza* OR neonotonia* OR macroptilium* OR macrotyloma* OR desmanthus* OR Medicago* OR trifolium* OR ryegrass* OR lolium*) #1.2 - TS=(chickpea* OR "common bean*" OR cowpea* OR peanut* OR soybean* OR rice* OR "tomato production*" OR chicken* OR poultry* OR propolis* OR "citrus management*" OR sanguinalis* OR "ARACHIS HYPOGAEA*") #1.3 - #1.1 NOT #1.2 #1.4 – SO[(2)]=(INDUSTRIAL CROPS*) #1 - #1.3 NOT #1.4
#2 – Cultivated pastures	#2.1 - TS= (cultivated* OR exotic* OR Panicum* OR Brachiaria* OR Andropogon* OR Pennisetum* OR Cynodon* OR Cenchrus* OR Digitaria* OR Setaria* OR Hemarthria* OR Chloris*) #2 - #2.1 AND #1
#3 - Natural pastures	#3.1 - TS= (native* OR natural* OR rangeland* OR Paspalum*) #3.2 - TS= ("natural herbicide*" OR "natural antioxidants*" OR "natural gas*") #3.3 - #3.1 NOT #3.2 #3 - #3.3 AND #1
#4 - Legumes	#4.1 - TS= (leguminoseae * OR legume* OR Stylosanthes* OR Arachis* OR Cajanus* OR Leucaena* OR Medicago* OR calopogonium* OR lespedeza* OR neonotonia* OR macroptilium* OR macrotyloma* OR desmanthus* OR Trifolium* NOT "ARACHIS HYPOGAEA*") #4.2 - TS= ("natural herbicide*" OR "natural antioxidants*" OR "natural gas*") #4.3 - #4.1 NOT #4.2 #4 - #4.3 AND #1
#5 – Tropical grasses	#5.1 - TS= ("tropical grass*" OR "C4* grass*" OR "tropical gramineae*" OR "C4* gramineae*" OR "summer grass*" OR "warm-season* grass*" OR Panicum* OR Brachiaria* OR Andropogon* OR Pennisetum* OR Cynodon* OR Cenchrus* OR Paspalum* OR Digitaria* OR "Setaria italica*" OR "setaria sphacelata*" OR Hemarthria* OR Chloris*) #5 - #5.1 AND #1
#6 – Temperate and subtropical grasses	#6.1 - TS=("C3* grass" OR "temperate grass*" OR "subtropical grass*" OR "C3* Gramineae" OR "temperate Gramineae*" OR "subtropical Gramineae*" OR "winter grass*" OR "cool-season* grass*" OR ryegrass* OR Lolium*) #6 - #6.1 AND #1
#7 – Pre-breeding	#7.1 - TS=("pre-breeding*" OR collection* OR "phenotypic characterization*" OR "cytogenetic characterization*" OR "molecular characterization*" OR "germoplasm characterization*" OR "descriptors characterization*"OR "tracer characterization*" OR genomics* OR proteomics* OR "genetic transformation*" OR biotechnology* OR "germplasm bank*") #7 - #7.1 AND #1
#8 – Plant breeding	#8.1 - TS=("development of cultivars*" OR "plant breeding*") #8 - #8.1 AND #1

Identification	Search expression
#9 – Which problem breeding programs are focusing on?	#9.1 - TS= (“development of cultivars*” OR “plant breeding*”) #9.2 - TS= (“global climate change*” OR diversification* OR intensification* OR sustainability* OR quality* OR “nutritive value*” OR nutrition* OR feeding * OR “feed supplementation*” OR digestibility* OR ideotypes*) #9.3 - #9.1 AND #9.2 #9 - #9.3 AND #1
#10 – Grazing management	#10.1 - TS= (“grazing management*” OR “harvest management*” OR “defoliation management*” OR frequency* OR intensity* OR timing* OR “grazing ecology*” OR ecophysiology* OR “soil plant and animal interface*”) #10 - #10.1 AND #1
#11 – Pastures restoration in Brazilian biomas	#11.1 – TI(3)= (recuperation* OR reform* OR renovation* OR “recuperation degraded areas*” OR establishment* OR degradation* OR desertification* OR “vegetative propagation*” OR implantation* OR sowing* OR seeding* OR “vegetative propagation*” OR springs* OR planting* OR stolon* OR rhizome* OR “stem cuttings*”) #11.2 - TS=(caatinga* OR semiarid* OR cerrado* OR amazonia* OR pampas* OR pantanal*) #11.3 - #11.1 AND #11.2 #11 - #11.3 AND #1
#12 – Forage quality and feed suplementation	#12.1 - TI=(“feed supplementation*” OR quality* OR “nutritive value*” OR digestibility* OR feeding*) #12 - #12.1 AND #1
#13 – Forage conservation	#13.1 - TI=(silage* OR hay* OR haylage* OR additives*) #13 - #13.1 AND #1
#14 – Production systems	#14.1 - TI=(“ production system*" OR “information management*” OR intensification* OR sustainability*) #14 - #14.1 AND #1
#15 – Seed technology	#15.1 - TI= (“seed technology*” OR “seed production*” OR “seedling production*”) #15 - #15.1 AND #1
#16 - Stress	#16.1 - TS= (“biotic stress*” OR pest* OR insect* OR spittlebug* OR “brown bug*” OR disease*OR pathogen* OR weeds* OR “abiotic stress*” OR “water stress*” OR drought* OR “water deficit*” OR flooding* OR anoxia* OR cold* OR freezing* OR heat* OR fire* OR aluminium* OR phosphorous* OR “mineral nutrients*” OR heat* OR fire*) #16 - #16.1 AND #1
#17 – Soil science	#17.1 - TI= (“soil fertility*” OR “soil conservation*” OR fertilizer* OR lime* OR “biological nitrogen fixation*” OR BNF* OR diazotrophic* OR azospirillum* OR rhizobium* OR inoculant* OR nodulation* OR “growth-promoters*” OR mycorrhiza* OR carbon* OR “organic matter *”OR “soil conservation*” OR erosion* OR “soil physics*” OR compaction* OR “mineral nutrition*” OR nitrogen* OR phosphorous* OR potassium* OR calcium* OR magnesium* OR sulphur* OR micronutrients*) #17 - #17.1 AND #1
#18 – Water use and conservation	#18.1 - TI= ("water conservation*" OR "water management*" OR “irrigation*” OR “crop coefficient” OR "water use efficiency*" OR “water footprint*") #18 - #18.1 AND #1
#19 - Automation	#19.1 - TS= (“mechanization agriculture *” OR “precision agriculture*” OR “automation agriculture*”) #19 - #19.1 AND #1
#20 – Climate changes	#20.1 - TS= (“global climate changes*” OR GLC* OR “climate changes*” OR adaptation* OR mitigation* OR “green house gases*” OR GHG* OR “carbon sequestration*” OR “carbon balance*” OR methane* OR resilience*) #20 - #20.1 AND #1

Identification	Search expression
#21 – Agroclimatic zoning	#21.1 - TS=("Edaphoclimatic zoning*" OR "agroclimatic zoning*" OR "agroecological zoning*" OR "climatic risk*" OR "climatic aptitude*" OR "agroclimatic aptitude*") #21 - #21.1 AND #1
#22 – Integrated systems	#22.1 - TS=(agroforestry* OR "crop-livestock integrated systems*" OR "silvopastoral systems*"OR "Pasture intercropped*" OR "grass legumes combinations*") #22 - #22.1 AND #1
#23 - modeling	#23.1 - TS=(modeling* simulation*) #23 - #23.1 AND #1

(1) TS = "Topic"; search for the specified word in the fields "title", "abstract", "authors' keywords", "Keywords Plus®" (keywords determined by the database)".

(2) SO = search for the specified word in the field "publication name".

(3) TI = search for the specified word in the field "title".

Search was applied to the Web of Science™ Core Collection (Science Citation Index Expanded (SCI-EXPANDED), Conference Proceedings Citation Index-Science (CPCI-S), and Emerging Sources Citation Index (ESCI)), due to its multidisciplinary characteristic, indexing publications on Agricultural and Food Technology, Chemistry, Biology, Environmental Science, Microbiology and other related areas (THONSON, 2016). Publications as papers, chapters of book, letters, meetings proceedings, notes and reviews were considered. The period of the search was from 2005 to 2015. All searches were filtered by Agriculture and Plant Sciences research areas, as those were the areas, according to Web of Science classification, where most records of grass and forage science could be found.

A total of 51,256 publications were recovered and prepared to be imported to the software Vantagepoint®, cleaning repeated publications and standardizing data like name of institutions and countries. After that, all database was imported to the software Vantagepoint®, where a thesaurus was created. The following indicators on science and technology on grass and forage science were developed and analyzed: whole number of records indexed by the Web of Science; number of records with authors from Embrapa; keywords informed by the authors; twenty most frequent keywords informed by authors; the number of records by country and institution; international collaboration on grass and forage research on Brazilian institutions.

2 Changes on grass and forage science from 2005 to 2015

Scientific production indexed in the Web of Science between 2005 and 2015 about "natural pastures" (6,231 records recovered) was higher than that about "cultivated pastures" (4532 records recovered), but number of records increased for both topics at almost the same rate during the period (Figure 1). At Embrapa, research on cultivated and natural pastures also increased between 2005 and 2015, but research on cultivated pastures was much more relevant along the role period (Figure 1)).

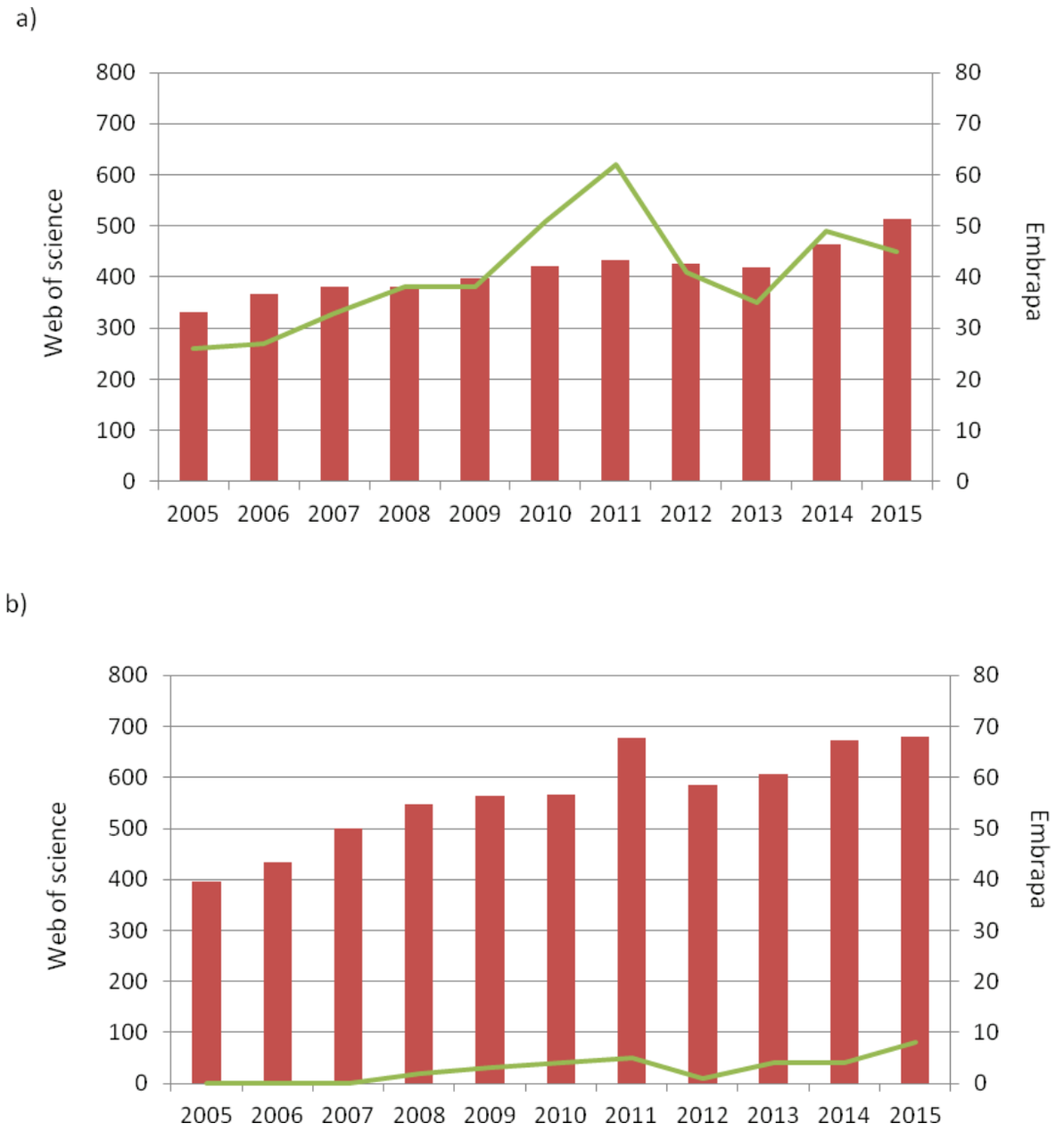


Figure 1. Whole number of records indexed by the Web of Science (bars) and number of records with authors from Embrapa (line) about cultivated (a) and natural pastures (b) between 2005 and 2015. Search strategy was applied to the fields "title", "abstract", "authors' keywords", "Keywords Plus®" (keywords determined by the database)".

Scientific production on legumes (7,702 records recovered) is higher than that on tropical (5,099 records recovered) and temperate and subtropical grasses (5,414 records recovered). On the other hand, records on tropical grasses increased at a higher rate than those on legumes and temperate and subtropical grasses (Figure 2). At Embrapa, research about tropical grasses increased in the same period (from 24 to 46 records per year between 2005 and 2015; Figure 2) and seemed to be more relevant than research about legumes (15 records recovered in 2015; Figure 2) and temperate and subtropical grasses (10 records recovered in 2015; Figure 2).

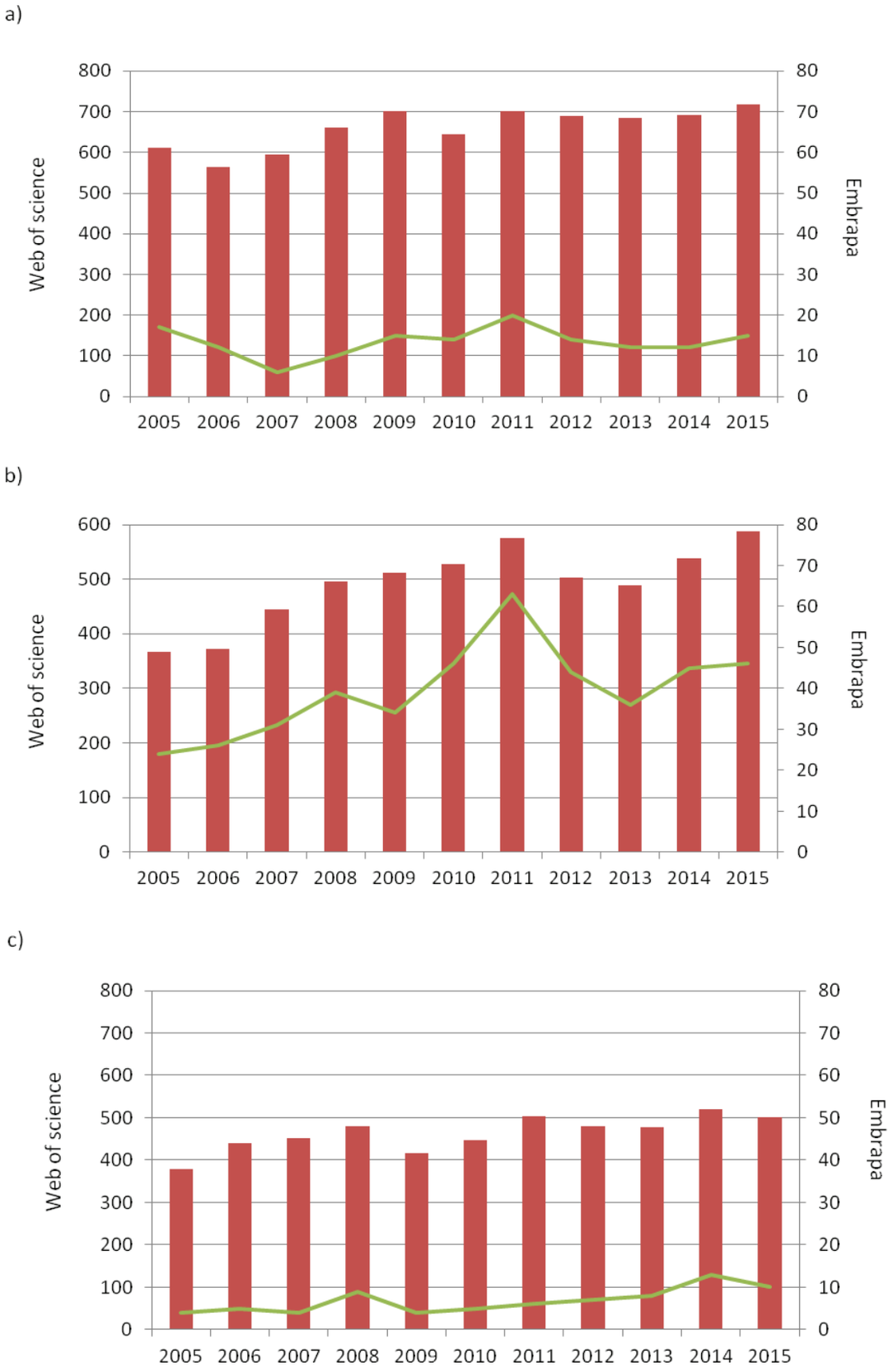


Figure 2. Whole number of records indexed by the Web of Science (bars) and number of records with authors from Embrapa (line) about legumes (a), tropical grasses (b), and temperate and subtropical grasses (c) between 2005 and 2015. Search strategy was applied to the fields “title”, “abstract”, “authors’ keywords”, “Keywords Plus®” (keywords determined by the database)”.

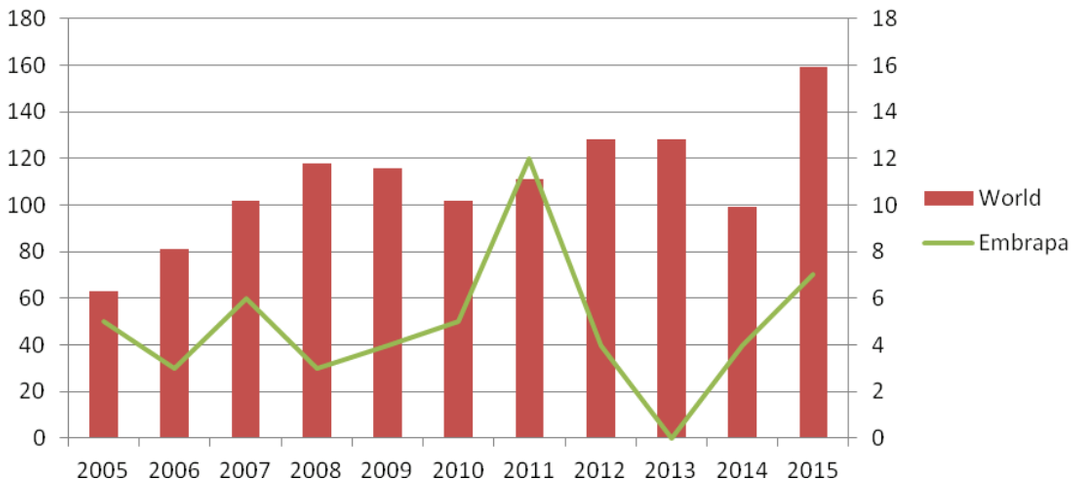
Among traditionally investigated topics on grass and forage science, increases on records were observed for plant pre-breeding and breeding (Figure 3a), and production systems (Figure 3b). Number of records recovered about plant pre-breeding and breeding from Embrapa increased between 2005 and 2015, but was very variable along the period (Figure 3a). Number of records about production systems with authors from Embrapa varied along the period and no clear tendency could be observed (Figure 3b).

Embrapa maintains germplasm banks, coordinates relevant breeding programs on forage grasses and legumes, and was responsible for the development of most cultivars of forage species planted in Brazil nowadays. Public-private partnership contributes to the competitiveness of the breeding programs.

Records on grazing management, forage quality and feed supplementation, forage conservation, and pasture restoration in typical Brazilian biomes increased slightly or were maintained constant (Figures 3c; d; f). At Embrapa, research about pasture management tended to increased along the period and was higher between 2009 and 2012. On the other hand, research about forage conservation and forage quality remained stable between 2005 and 2015 (Figures 3c; d; f).

Most records about pasture restoration are related to semiarid areas (29 out of 39 records), with most of them originally from China. In Brazil, most records about pasture restoration are related to the Cerrado biome (5 out of 39 records). It was not possible to evaluate tendencies about research on pasture restoration at Embrapa, because few records were recovered. The reduction of degraded pastureland area is one of the Brazilian strategies to reduce its greenhouse gases emissions, and the country has been investing in research, development, and transfer of technology to achieve this goal. Despite that, results obtained here do not indicate an increase in research on this topic, suggesting the need to improve the search strategy to recover records. Initiatives on pasture restoration in Brazil have been focusing on crop-livestock integrated systems, but these terms were not considered in the search expression for pasture restoration. Besides that, the search expression was applied just to the field “title”, as keywords represented general terms broadly used to describe material and methods of experiments, and some important information may have been lost.

a)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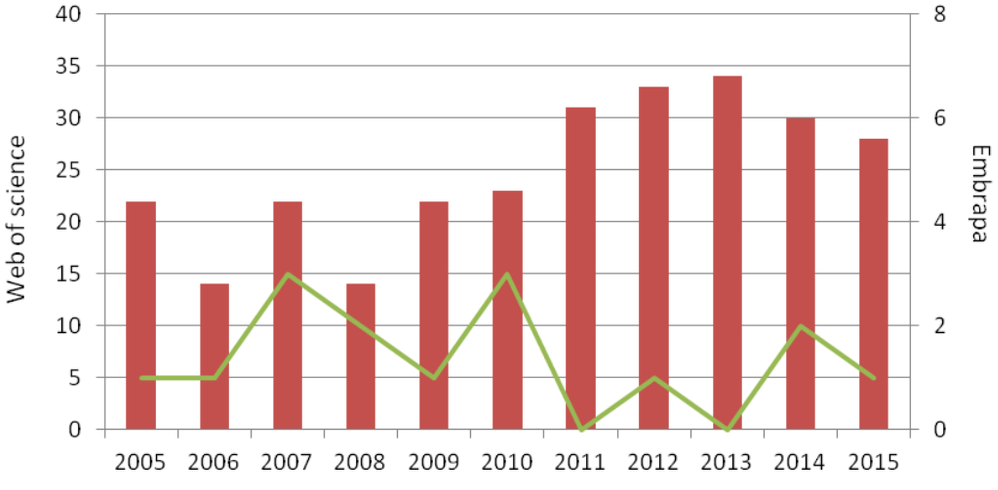
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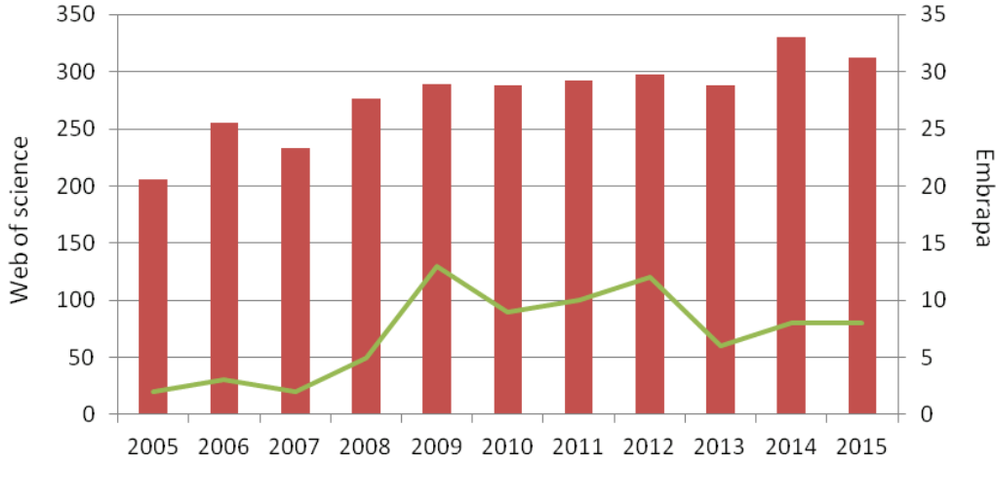
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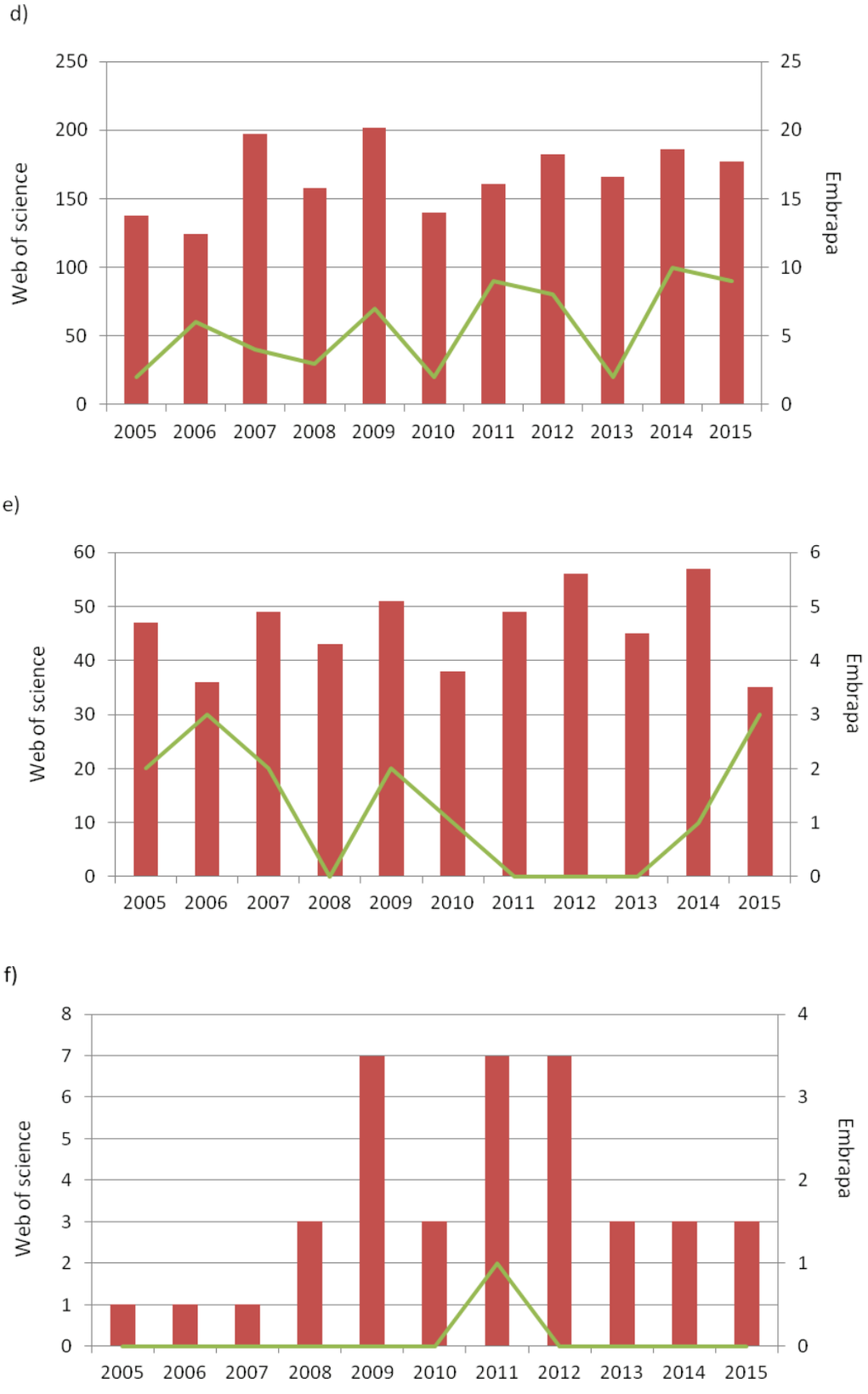
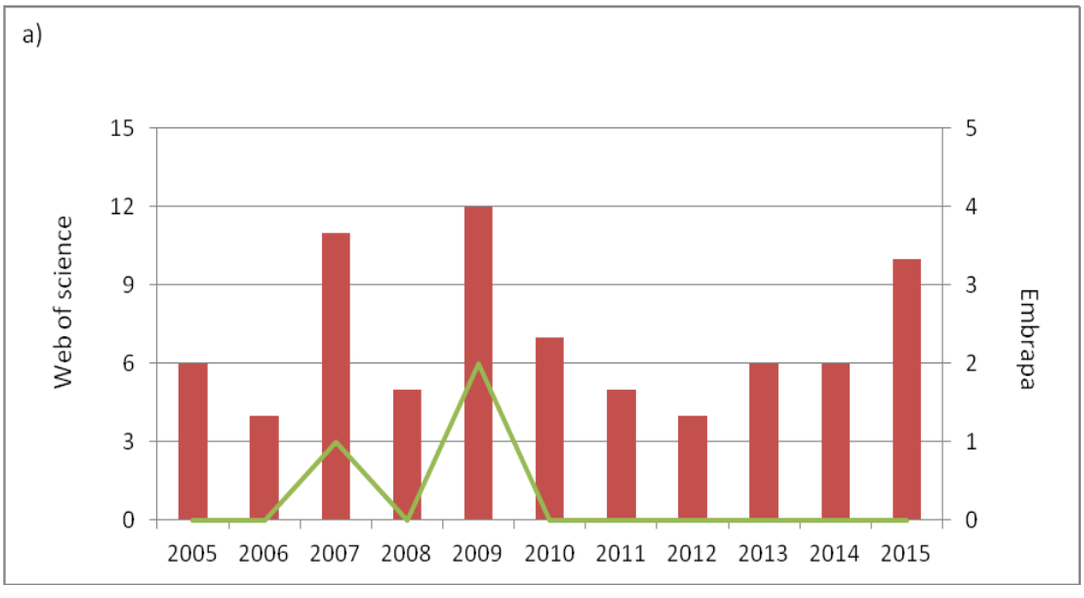
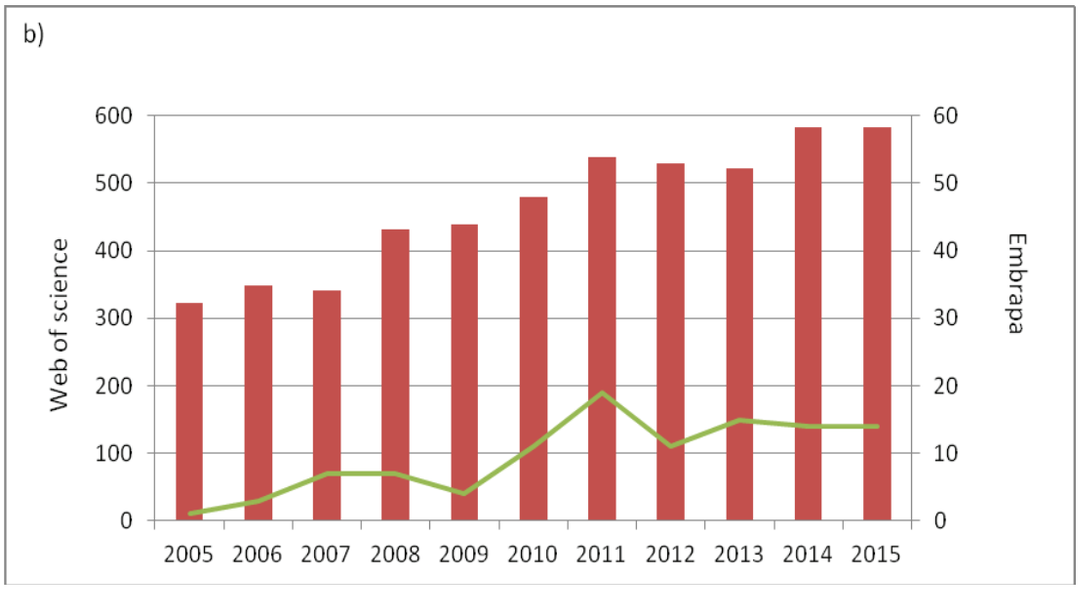


Figure 3. Whole number of records indexed by the Web of Science (bars) and number of records with authors from Embrapa (line) about pre breeding and plant breeding (a), production systems (b), grazing management (c), forage quality and feed supplementation (d), forage conservation (e), and pasture restoration in Brazilian biomes (f), between 2005 and 2015. For pre breeding, plant breeding and grazing management search strategy was applied to the fields “title”, “abstract”, “authors’ keywords”, “Keywords Plus®” (keywords determined by the database)”. For production systems, forage quality and feed supplementation,forage conservation, and pastures restoration in Brazillian biomas search strategy was applied to the field “title”.

Records on transversal and multidisciplinary topics traditionally investigated on agronomic crops like soil science, water use and conservation, and stress, increased between 2005 and 2015 (Figure 4). Numbers of records on seed technology were very variable during this period and no clear tendency could be observed. Embrapa did not follow the increase in the number of records about water observed in the world (Figure 4d). On the other hand, the increase on records about stress and soil science was also observed at Embrapa. Although the relevance of tropical forage seeds market in Brazil, seed technology does not seem to be a relevant topic of research on grass and forage science at Embrapa.





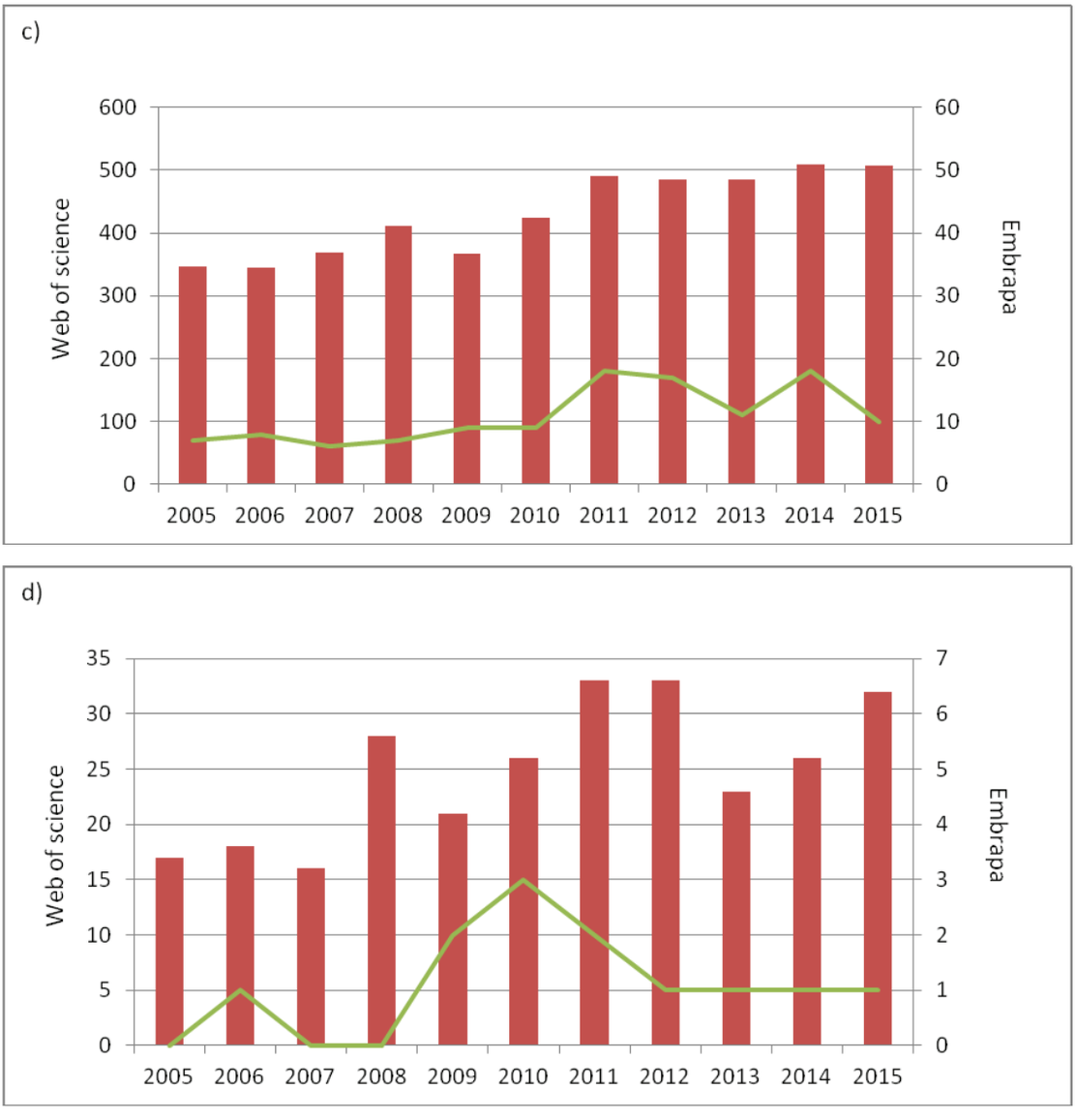
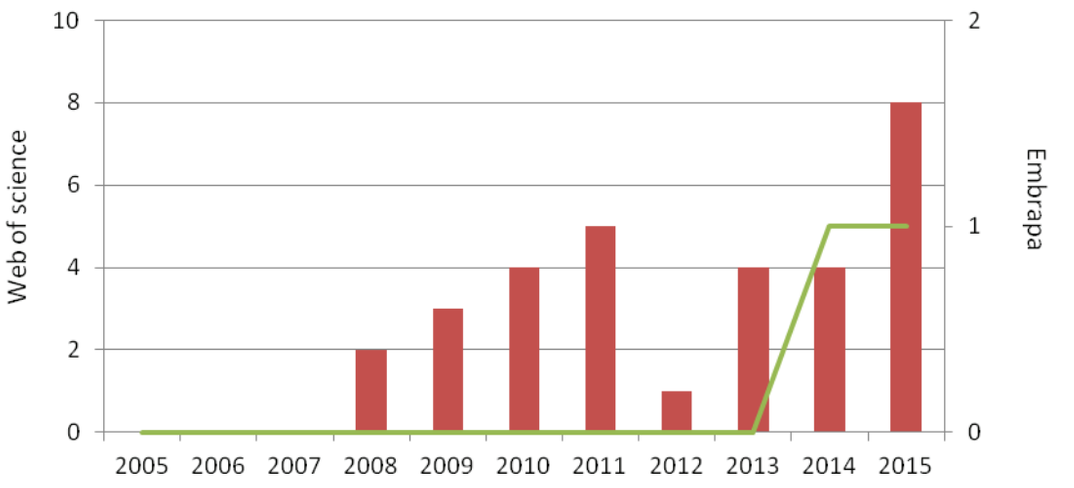


Figure 4. Whole number of records indexed by the Web of Science (bars) and number of records with authors from Embrapa (line) about seed technology (a), stress (b), soil science (c), water use and conservation (d), between 2005 and 2015. For stress search strategy was applied to the fields "title", "abstract", "authors' keywords", "Keywords Plus®" (keywords determined by the database)". For seed technology, soil science and water use and conservation search strategy was applied to the field "title".

Among topics which are related to new challenges that pasture-based-animal production sector are facing nowadays, the most significant changes were on records about climate change, but increases on records about automation and modeling were also observed (Figure 5). At Embrapa, research about climate change also increased between 2005 and 2015, but few records were recovered about automation, agroclimatic zoning and modeling related to grass and forage science.

a)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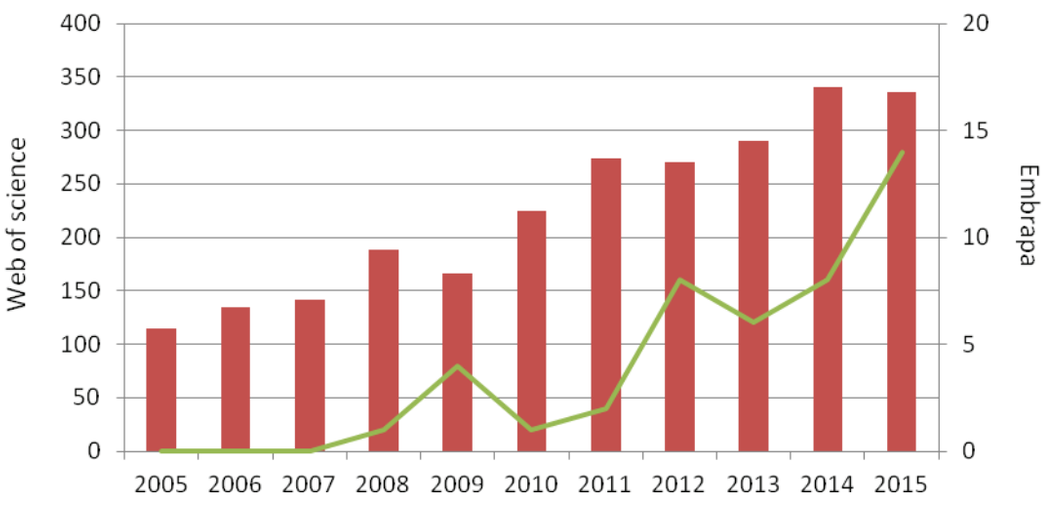
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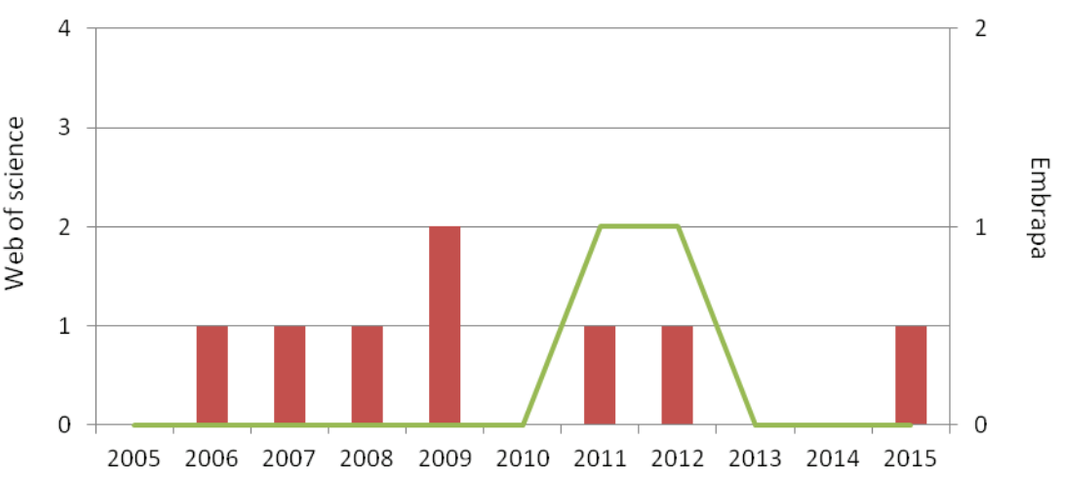
c)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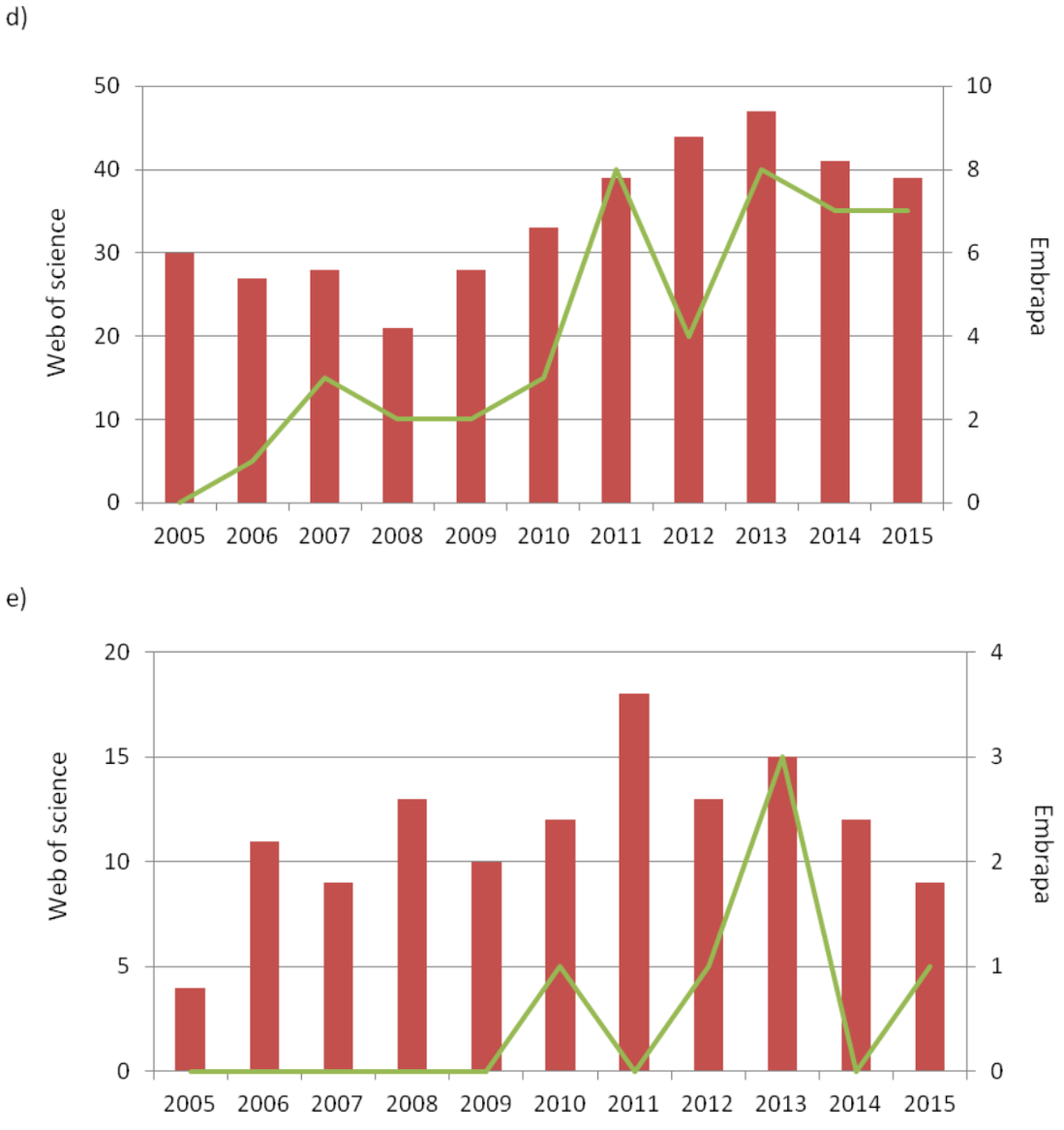

Figure 5. Whole number of records indexed by the Web of Science (bars) and number of records with authors from Embrapa (line) about automation (a), climate changes (b), agroclimatic zoning (c), integrated systems (d), modeling (e), between 2005 and 2015. Search strategy was applied to the fields "title", "abstract", "authors' keywords", "Keywords Plus®" (keywords determined by the database)".

3 Keywords informed by authors and the main topics of research

The most frequent keywords informed by authors were "grassland", "pasture", "graze", and "nitrogen", each cited more than 500 times on the records recovered. Besides that, the following keywords were also very frequent (cited around 300 times on the records recovered): sheep, phosphorous, biodiversity, forage, legume, cattle, alfalfa, climate change, grass, dairy cow, land use, competition, *Medicago truncatula*, fertility, digestate, nitrous oxide. Keywords informed by authors give an idea about the approach and the most relevant topics of investigation. Some of these keywords are general terms used on grass and forage science (e.g. grassland, pasture, graze, cattle, forage, legume, cattle, grass), and others point out the relevance of some topics, like mineral nutrition of

plants (nitrogen, phosphorous), genetic resources (biodiversity, alfalfa), and climate change (climate change, nitrous oxide, land use).

The analysis of the most frequent keywords informed by authors by topic gives a better view of what have been investigated recently (Table 2). For temperate and subtropical grass, *Lolium perenne* and *Lolium multiflorum* are the most studied species, followed by tall fescue (*Festuca arundinaceae*). *Brachiaria* and *Panicum* are the most studied genus of tropical grasses, followed by *Pennisetum* and *Cynodon*. For both temperate and subtropical kinds of grass and tropical grass, mineral nutrition, pasture management, and weed competition are relevant topics of research. Besides that, forage quality seems to be a relevant research topic on tropical grasses. Species of *Medicago* and *Trifolium* genus are the most studied legumes, followed by *Cajanus cajan*. Mineral nutrition and symbiosis with microorganisms (mycorrhiza and rhizobium) are relevant topics of research on legumes.

Biodiversity, land use, invasive species, organic matter, and climate change, are among the main topics of research on natural pastures. Research on cultivated pastures focuses on *Brachiaria*, *Panicum*, *Pennisetum* and *Cynodon* species; besides that, the main topics are about mineral nutrition (nitrogen), forage quality, and weed competition.

Medicago trunculata is an important species for pre-breeding research, and biodiversity, “omics” science, molecular markers and plants transformation seems to be the main topics of research on this theme. *Lolium*, *Trifolium*, and *Medicago* are the principal genera informed by authors on records about plant breeding, and the focus of research on this theme seems to be biodiversity, abiotic stress, apomixis, biofuel, and development of new cultivar.

Intensification of production systems seems to be an essential problem approached through plant breeding; from a total of 146 records recovered related to plant breeding, the word intensification appears on 59 records.

Besides topics directly related to grazing management, like grazing intensity and stocking rate, research about this topic seems to be related to mineral nutrition (nitrogen and phosphorous), climate change, biodiversity, modeling, competition, and land use. Alfalfa was the forage species most cited on records about grazing management.

Desertification, land use change, Amazon basin, *Brachiaria brizantha*, overgrazing, and phosphorous are the most frequent keywords on records about pasture restoration. Besides that, semi-arid grasslands and soil characteristics are relevant topics of research on these topics.

Intake, nutrition value, crude protein, and fatty acid seem to be the most investigated topics on research about forage quality and feed supplementation. Sheep were the most frequent animal species cited as a keyword on these records, but goat, dairy and beef cattle were among the 20 most cited keywords. The influence of forage quality and feed supplementation on meat quality and the relationship between soil quality and forage quality are also important themes on these research topics.

Silage and topics related to it, like fermentation, lactic acid bacteria, and aerobic stability, are the main focus of research on forage conservation. Most research about forage conservation is related to dairy cattle, but goat and sheep were also among the 20 most cited keywords. *Pennisetum purpureum* and alfalfa were the most cited among the plant species used for forage conservation.

Research on production systems focus on beef and dairy cattle and it is highly concerned about sustainability. The most frequent keywords recovered on seed technology records suggest that the

main focus of this theme is on seed production; although topics like dormancy seem to be also relevant. Alfalfa was the most cited plant species on records about seed technology.

Drought stress, weeds competition, defoliation, fire, and nitrogen were the most cited causes of stress cited on records evaluated. Global climate change and biodiversity are essential topics on research about stress on forage plants. The most cited plant species on stress studies were alfalfa and *Lolium perenne*.

Nitrogen, soil organic matter and carbon sequestration, mycorrhizal fungi, phosphorous, climate change, and greenhouse gases emissions (nitrous oxide), and legumes are the main topics of research on soil science.

Research about water use and conservation focus on irrigation, and on parameters related to water availability and use (water use efficiency, evapotranspiration, soil water, and deficit). The relationship between water and mineral nutrition (nitrogen and phosphorous) is also investigated. The most cited plant species on studies about water were alfalfa and *Lolium perenne*.

Precision agriculture and its tools seem to be the main topic of research about automation, but topics like mechanization and sustainability were also among the main cited keywords on records evaluated.

Research related to global climate changes focus on carbon balance (greenhouse gases emissions and carbon sequestration), and on adaptation of production systems. Most keywords on agroclimatic zoning records are related to climate risk and abiotic stress.

Carbon sequestration, nitrogen, competition between plants (light, mineral nutrients, allelopathy), sustainability, and land use are the main topics of research on integrated production systems.

Simulation models were the most cited on records about modeling. The high frequency of words like climate change, swat, soil organic carbon, land use, sediment, and water quality suggests that modeling have been widely used to investigate environmental impacts of grasslands.

Table 2. Most frequent keywords informed by authors on each theme.

Theme	Keywords (ten more frequent)	Keywords (next ten more cited)
Legumes	Legume, alfalfa, *Medicago truncatula*, *Medicago sativa*, nodule, arbuscular mycorrhiza, nitrogen, *Trifolium repens*, Lucerne, symbiosis	Red clover, grassland, pigeon pea, pasture, nitrogen fixation, white clover, forage, grass, phosphorus, goat
Tropical grass	Switchgrass, *Brachiaria brizantha*, *Panicum maximum*, pearl millet, grass, digestate, forage, nitrogen, pasture, *Pennisetum glaucum*	*Pennisetum purpureum*, Poaceae, *Brachiaria decumbens*, biomass, bermudagrass, graze, turfgrass, *Cynodon dactylon*, weed, tropical grass
Temperate and subtropical grass	*Lolium perenne*, perennial ryegrass, ryegrass, herbicide resistance, grassland, graze, nitrogen, *Lolium multiflorum*, grass, pasture	Dairy cow, forage, tall fescue, sheep, endophyte, legume, allelopathy, phosphorus, white clover, silage
Cultivated pasture	Switchgrass, *Brachiaria brizantha*, *Panicum maximum*, pasture, nitrogen, pearl millet, digestate, grass, forage, *Pennisetum glaucum*	*Pennisetum purpureum*, *Brachiaria decumbens*, graze, grassland, Poaceae, competition, biomass, bermudagrass, weed, *Cynodon dactylon*
Natural pasture	Grassland, graze, pasture, biodiversity, nitrogen, land use, rangeland, land use change, competition, invasive species	Species-rich, soil organic carbon, climate change, restorers, sheep, diversity, semi-natural grassland, soil organic matter, cattle, grass
Pre-breeding	*Medicago truncatula*, genetic diversity, proteome, genetic transformation, genetic resource, alfalfa, legume, digestate, genome, germplasm	Somatic embryogenesis, molecular marker, diversity, grassland, pasture, plant breeding, sheep, *Lolium perenne*, perennial ryegrass, breed
Plant breeding	Plant breeding, genetic diversity, *Lolium perenne*, perennial ryegrass, drought, forage legume, morphology, pasture, *Trifolium repens*, white clover	Abiotic stress, alfalfa, apomixis, biofuel, biomass, cultivar, endophyte, forage, forage grass, grass
Grazing management	Grassland, graze, managed grazing, pasture, nitrogen, climate change, biodiversity, phosphorus, grazing intensity, model	Dairy cow, competition, cattle, stocking rate, management, land use, nitrous oxide, alfalfa, disturbance, sheep
Pasture restoration	Desertification, land use change, Amazon basin, *Brachiaria brizantha*, Colombia, degraded pasture, ecosystem, overgrazing, phosphorus, phosphorus forms	Restorers, semi-arid grassland, soil aggregate, soil organic matter, soil texture, tropic pasture, 13-C natural abundance, abandoned cropland, abandoned land, above- and below-ground biomass
Forage quality and feed supplementation	Digestate, pasture, graze, nutrition value, intake, sheep, forage, crude protein, forage quality, fatty acid	Goat, dairy cow, meat quality, supplement, nitrogen, grassland, soil quality, beef, cattle, chemical composition
Forage conservation	Silage, digestate, intake, dairy cow, fermentation, nutrition value, grass silage, lactic acid bacteria, hay, pasture	*Pennisetum purpureum*, fatty acid, forage, goat, alfalfa, milk products, sheep, aerobic stability, grass, graze
Production systems	Grazing, pasture, beef cattle, sustainability, grassland, dairy, environment, stocking rate, beef, dairy cow	Economics, production system, dairy cattle, fatty acids, forage, nitrogen, simulation, beef production, carbon footprint, nitrous oxide
Seed technology	Seed yield, seed production, germination, alfalfa, nitrogen, red clover, restoration ecology, seed yield component, weed management, boron	Demography, dormancy, fertile stem density, forest site utilization, genetic resource, grass seed crop production, irrigated, legume, Leguminosae, lodging

Theme	Keywords (ten more frequent)	Keywords (next ten more cited)
Stress	Grassland, drought, climate change, weed, graze, fire, competition, pasture, alfalfa, nitrogen	Biodiversity, abiotic stress, germination, grass, herbicide, herbicide resistance, water stress, legume, *Lolium perenne*, photosynthesis
Soil	Nitrogen, grassland, soil organic carbon, arbuscular mycorrhiza, soil organic matter, carbon sequestration, pasture, land use, arbuscular mycorrhizal fungi, fertility	Phosphorus, land use change, microbial biomass, nitrogen fertility, climate change, nitrous oxide, carbon, legume, graze, nitrate
Water	Irrigated, water use efficiency, alfalfa, evapotranspiration, pasture, nitrogen, *Pennisetum purpureum*, phosphorus, soil water, deficit irrigation	Grass, photosynthesis, transpiration, yield, drip irrigation, evaporation, forage quality, maize, restorers, switchgrass
Integrated production system (including grass-legumes combinations)	Agroforestry, silvopastoral systems, agroforestry systems, silvopastoral system, carbon sequestration, intercropping, silvopasture, soil organic carbon, nitrogen, competition	Sustainability, shade, legumes, biodiversity, soil fertility, silvopastoral, land use, alley cropping, biomass, allelopathy
Climate change	Methane, carbon sequestration, grassland, nitrous oxide, climate change, pasture, soil organic carbon, graze, adaption, greenhouse gas	Sheep, nitrogen, carbon oxide, land use change, mitigation, model, greenhouse gases, land use, legume
Automation	Precision agriculture, geostatistics, pasture, grassland, ordinary cringing, remote sensing, apparent soil electrical conductivity, biotechnology, breed, economic	Fertile soils, graze, managed pasture, phosphorus, principal component analysis, soil management, sustainable agriculture, agriculture mechanization, agroecology, allelopathy
Agroclimatic zoning	Abiotic stress, agriclim, agroclimatic zones, agrotain, alley farming, animal urine, *Brachiaria brizantha*, climate change, climatic risk, climatic variables	Continuous cropping, crop model, dicyandiamide, drought, efficient frontier, evapotranspiration, growing season, integrated crop-livestock production, integrated crop-livestock system, low rainfall cropping
Modeling	Modeling, simulation, simulation modeling, swat, climate change, evapotranspiration, grassland, nitrogen, simulation model, soil organic carbon	Grazing, land use, model, pasture, sediment, switchgrass, water quality, biomass, climate, conservation tillage

4 The main players on grass and forage science in the world

The leading institutions on grass and forage science in the word are USDA-EUA, INRA-FR, EMBRAPA-BR, and The Chinese Academy of Science-CHN (Figure 6). There was also an increase on the number of records from Chinese Academy of Science, Embrapa-BR, Noble Research Institute-EUA, University of São Paulo-BR, Gottingen Institute-GER, Lincoln University-NZ, and Wageningen UR-NL from 2005-2010 to 2011-2015. The number of records from Universidade Federal de Viçosa-BR and the University of Florida-EUA decreased in the same period (Figure 6).

In Brazil, the leading institutions on grass and forage science are Embrapa (24% of records), UFV (14% of records), Unesp (13% of records), USP (13% of records) e UFRGS (10% of records).

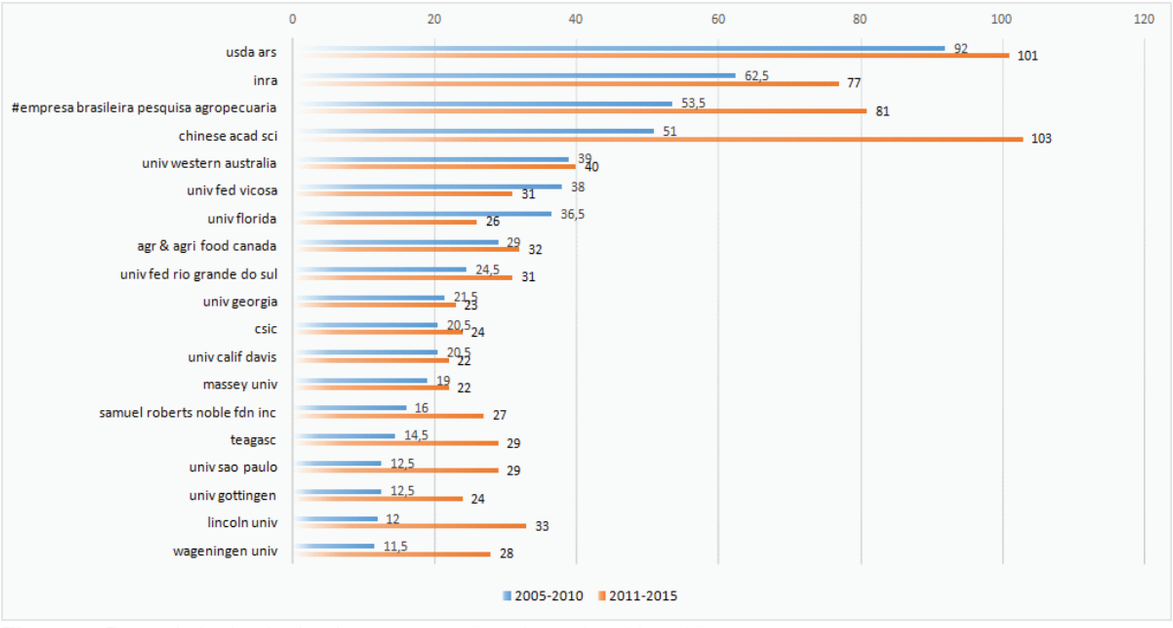

Figure 6. Records by institution between 2005-2010 and 2011-2015.

The leading country on grass and forage science in the world is the EUA (5507 records), followed by Australia (5072 records), Brazil (3084 records), China (2048 records), and Germany (1666 records). In Brazil, just 16.7% of records were published in collaboration with researchers from other countries, mainly from EUA, Australia, China, Germany, France, New Zealand, Spain, India, Canada, and England. Among Brazilian institutions with a consistent scientific production on grass and forage science, USP and UFRGS are those with highest international collaboration (23 and 22% of papers recovered were written with international collaboration, respectively).

At Embrapa, 17% of records were published in collaboration with researchers from other countries, mainly from United States (6% of records), France (3% of records), Australia (2% of records), Spain, Argentina, Canada, Germany, and Uruguay (around 1% of records).

5 Final considerations about grass and forage research at Embrapa

Embrapa is one of the leading institutions on grass and forage science in Brazil and in the world. Research on grass and forage science at Embrapa follows most of the main trends in the world. Effort should be made to improve research on natural pastures, mainly in vulnerable biomes, like Caatinga, Pantanal, and Campos Sulinos, to guarantee sustainable animal production in these areas. Research on seed technology should also be reinforced, due to the importance of tropical grasses seed market in Brazil.

Brazil is one of the leading cattle and beef producers in the world. Most of the Brazilian cattle herd is raised and finished on pasture. During the past decades, the use of improved forage germplasm and better pasture management strategies contributed to the increased performance of the Brazilian cattle ranching industry (MARTHA JUNIOR; ALVES; CONTINI, 2012). However, despite this considerable improvement in performance, the average pasture productivity in Brazil is still below its potential (DIAS-FILHO, 2014; OLIVEIRA et al., 2018).

An important cause of this low productivity is the area of degraded pastures, estimated in about 50% of the total pasture areas in Brazil (Dias-Filho, 2014). It was not possible to evaluate properly tendencies about research on pasture restoration because few records were recovered, but grass and forage research plays a role in reversing this trend, providing the basis for a continuous sustainable improvement of pasturelands in Brazil. The reclamation of degraded pastures is critical in this improvement process, increasing productivity, using already cleared areas, currently abandoned, or underutilized, reducing deforestation and making the Brazilian cattle ranching industry more productive and sustainable.

To achieve this objective, current and future grass and forage research in Brazil should be based on actions that lead to increased food security, land (livestock) productivity, and environmental conservation, granting sustainable intensification of current pasturelands, reducing deforestation and the emissions of greenhouse gases.

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