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# Analysis of occupational accidents with agricultural machinery in the period 2008–2010 in Austria

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ABSTRACT

The number of serious accidents at work, despite improved technology, coordinated prevention measures and better training and higher skill levels of farmers, is still very high in the Austrian agriculture and forestry. The scenarios in which people are injured are manifold. Parametric information of recognized accidents with different machines in agriculture and forestry in Austria in the years 2008–2010 was evaluated descriptively and analytically. This information included data about the accident victim, activity, accident course and cause as well as type of injury and the affected body parts by frequency and contexts. As analytical test method the chi-square test and odds ratio analysis were used. The aim was to determine the information content of parameters, in particular for the accident-causing human–machine interaction, from accident reports to derive prevention measures that meet the demand. The results showed that the information content of accident reports, because of insufficient information about the accident-causing human–machine interaction, does not suffice to derive or develop further sustainable preventive measures. Only through additional injury surveys and evaluations of accident and new machines was it possible to derive prevention measures meeting the demand according to accident course and cause.



## 1. Introduction

The number of serious accidents at work with some fatalities in agriculture and forestry is still very high in Austria. In the year 2013, 3,805 accidents occurred in the entire agricultural sector, 56 of them were fatal (SVB, 2013). Europe-wide, the number of fatal accidents at work in agriculture, hunting and forestry is higher than in any other sector. Only the number of fatal accidents at work in the construction industry is similarly high. Compared to agriculture, however, the number of fatal accidents in the construction industry decreases steadily (OSHA, 2012).

The accident scenarios in which people are injured are very varied in the agriculture and forestry sector. In spite of ever improving technology, coordinated prevention measures, better training and higher educational levels of farmers, the number of accidents at work is still very high. According to the ESAW statistics, the most common accidents (machine, human and animal accidents) occur by "slipping or stumbling and falling of a person", followed by "loss of control of the machine, means or transport or handling equipment, hand-held tool, object or animal" and "objects breaking, bursting, splitting, slipping, falling and collapsing" in the Austrian agriculture and forestry (SVB, 2013). For accidents with machinery between 2008 and 2010 the "loss of control of the machine, means or transport or handling equipment, hand-held tool or object", the "slipping or stumbling and falling of a person" and the "other movements of the body" were the most common causes. These statistics do not yield the relevant information about the accident-causing human–machine interaction in the technical terminology of agriculture and forestry, which is necessary to evaluate safety-related deficits (Kogler et al., 2014*).

Due to the diversity of the cultivated landscape and the high mechanization of farms (livestock, crop production, mixed farms, forestry and specialty crops) over one production year, different activities need to be performed in the Austrian agriculture. To do so, various machines and equipment are used, such as self-propelled, three-point linked, towed, stationary and hand-held machines. Because of the various machine types and design differences, the operating persons are subjected to diverse injury risks. Despite specific regulative requirements for safety design (Machinery Directive 2006/42/EC, DIN EN ISO 4254-1 and the respective machine type standard), the diverse machinery is subject to very strong signs of wear and tear in practice. In conjunction with careless maintenance and improper handling and operation, this poses a high injury risk for farmers.

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In Austria, the Social Insurance Institution of Farmers (Sozialversicherungsanstalt der Bauern (SVB, 2013) processes accident research, accident prevention, medical treatment as well as rehabilitation and compensation for farm managers, operating farm members (spouse, children, parents, brothers and sisters of farm managers), proprietors of hunting and fishing rights and other persons. The Austrian Workers Compensation Board (AUVA) processes accident prevention, medical treatment as well as rehabilitation and compensation for employed persons, students and children of pre-school age and voluntary organizations and lifesavers. Scientific research (in cooperation with other institutions) on different accident issues is constantly being carried out. The results are incorporated in accident prevention actions through professional journals, leaflets and information events (AUVA, 2012).

Databases (encoded form of accident reports), accident reports of insurance institutions, press releases from newspapers and police and hospital reports form the basis of accident research in Austria. The quality of information varies greatly and accident courses and causes as well as the accident-causing human–machine–environment interaction and the accident-causing machine part are not captured by one database in a professional sector specific way.

Due to the lack of information in the ESAW-compliant accident database, the aim of this study was to analyze the associated accident reports. The information deficits as regards the evaluated accident courses and causes were reduced by conducting additional injury surveys and evaluations of accident and new machines in order to derive and expedite prevention measures.

## 2. Material and methods

As the database of the descriptive and analytical accident analysis, the anonymous accident reports about recognized occupational accidents of the Social Insurance Institution of Farmers (SVB) and the Austrian Workers Compensation Board (AUVA) of the years 2008–2010 were used because they include the most accurately documented information about accident circumstances. Accidents at work are documented in accident reports more frequently and with a much higher information content than in press reports in Austria (AUVA, 2012). The data basis for the analysis were 1,927 reports about accidents with various machines and equipment in agriculture and forestry. Accident analyses are based worldwide on different databases (databases, accident, police, newspaper and hospital reports as well as local and injury surveys). In this study, accident reports were chosen because of the higher information content than in press, police and hospital reports (AUVA, 2012). A recognized occupational accident (according to ESAW methodology) is defined as a clearly defined event occurring during the work process and leading to physical or psychological damage that causes a minimum of three days' absence from work (Eurostat, 2012).

The 1,927 machine accidents were analyzed with the narrative text analysis method (Mayring, 2008) according to the identified variables (kind of machine, position of the person in the farm business, accident, task, accident course and cause, type of injury and affected body part) of the relevant text passages or tags. The variable "task" refers to the work process performed at the time of the accident. The variable "accident course" represents the exact events that led to the accident. The accident cause is defined by the exact specific reason that caused the accident. In addition, safety deficits, which are not listed in the Austrian accident reports, were derived from the available information about accident course and cause. The accident factors were classified into human, machine, environment, and the combination of these. The variable "others" includes sub variables that did not fit into any of the other categories due to low frequencies and differences.

According to Bunn et al. (2008), the narrative text analysis, which was also selected for the analysis of fatal tractor accidents in Kentucky, was chosen for the analysis of press reports. The filtered relevant text passages or keywords were entered into a spreadsheet program. The accident reports were largely completed by hand and did not contain coded information, so that the analysis was done manually and not computer-based. After entering the details of the accident reports, the categorization was carried out after existing literature (CAIR, 2012).

For the injury survey, machine-specific semi-structured questionnaires were created. The inquired contexts to clarify the lack of information about accident-causing man–machine–environment interaction were "machine, human and environmental accident factors", "aggravating and weakening factors of injury severity", "accident course", "proposals of construction changes and the integration of additional safety technologies into the machine and the operation". For the injury survey, a total of 201 (100%, 201/201) victims were interviewed according to machine category and circumstances of the accident. Additionally, existing accident machines and equipment on the farms (100%, 163/163) were evaluated as to their compliance with applicable directives and standards (same as for the evaluation of new machines) to identify any safety-related weaknesses and shortcomings as well as types and states of accident-causing machine parts.

The evaluation of new machinery (100%, 259/259) was carried out because a certain number of the accident machines corresponded to older models and safety weaknesses may even be present in new models. An evaluation questionnaire included the accident-relevant machine parts identified and divided according to accident scenarios, machine size, category, brand and type in relation to the applicable safety requirements of Machinery Directive 2006/42/EC, DIN EN ISO 4254-1 and the respective machine type standard. The information derived from the completed injury survey and machine evaluations was entered into the spreadsheet program Microsoft Excel, categorized and described in Word®.

The statistics program SAS 9.2® was used for the descriptive and analytical evaluation of the parameters of the accident reports. The chi-square test was used as the statistical method for testing significant correlations (contingencies) of qualitative (discrete) features. This statistical method had previously been used by Javadi and Rostami (2007), Linderoos et al. (2008) and Tsioras et al. (2012) for the analysis of machinery accidents in agriculture and forestry. The results were presented in cross tables.

As another method for statistical analysis, an Odds Ratio analysis, which represents a measure of the relationships of two features, was applied. Because of its very good interpretability, it is a preferred method in medical and accident statistics. Since its significance applies to only two features, it is used in combination with logistic regression to handle multivariate problems. It provides a sound mathematical foundation that helps to find the optimum dimension of attributes (variables), to explain an excellent and desired feature through other characteristics that need to be examined and to be able to neglect redundant ones (keyword: backward selection) (Weiß and Razany, 2008). In the model the variable injury severity was compared with personal-, accident-place- (workplace) accident-course and cause- as well as the affected body-part-specific parameters simultaneously and then gradually irrelevant parameters were removed. Only the significant statistical results of the Odds Ratio and the Chi-square test were described closer in the following sections.

The classification of the injury type according to severity (light and severe) was performed after Kanz et al., 2002. Light injuries included wounds and superficial injuries, dislocations, sprains and fractures, while severe injuries included burns, scalds, frostbites, poisoning, infections and amputations, injuries caused by

extreme temperatures, light and radiation, as well as paralysis and heart attacks.

## 3. Results and discussion

### 3.1. Involved machine types of recognized occupational accidents

For the period 2008–2010, 1,927 (59.0%), accident reports after the machines categories of Table 1 were provided for further accident analysis of the database results (100%, $n$ = 3,250) (Kogler et al., 2014*). Twenty-one of these accidents (1.09%, 21/1927) were fatal. The distribution of accidents into machinery categories after analyzing the accident reports showed that the most common accidents in the Austrian agriculture and forestry occurred with hand-held machines (37.0%, 713/1927), followed by three-point linked (27.2%, 525/1927), self-propelled (21.5%, 414/1927), towed (11,3%, 218/1927) and stationary machines (3.00%, 57/1927).

The most common light injuries (45.1%) occurred with hand-held and the most severe injuries with three-point linked machines (34.8%) ($p$-value 0.0001). Fatal accidents were significantly more likely to occur with self-propelled machinery (75.0%), followed by three-point linked (20.0%) and stationary machines (each 5.00%) ($p$-value 0.0001). The Odds Ratio showed a 2.69 times increased risk (Odds Ratio [OR] = 2.69, 95%; Confidence Interval [CI] = 2.04–3.55) for sustaining a severe injury for working with agricultural three-point linked machines compared to the other machine groups (self-propelled, hand-held, towed and stationary).

Through the comparison with the corresponding results from the evaluated database, it came to light that accidents most frequently occurred also with hand-held machines; however, the results from the database show that the self-propelled come second, the towed third and the three-point linked machines fourth (Kogler et al., 2014*). Regarding the details about accident-causing machine type from the database and accident reports, there is a similarly high quality of information according to the relative frequency of the accident-causing type of machine.

Regarding mechanical factors, from the performed injury survey it emerged that the accident machines were mostly over 10 years old and in some cases subjected to severe signs of wear and tear on the protective machine parts (covers), steps and ladders and machine-specific working tools. Through the machine evaluation, which was carried out according to specific regulations as to the safety design (Machinery Directive 2006/42/EC, DIN EN ISO 4254-1 and the respective machine type standard), deficiencies in machine labelling (marking) were found. A further lack of information on plaques and of warnings and instructions for accident and new machines could be identified in all machine types (self-propelled, towed, three-point linked, hand-held, stationary). These failures, in combination with the various machine types, design differences and inadequate maintenance, improper handling or operation, increase the injury risks for farmers (Quendler et al., 2014).

Comparative studies of fatal accidents in the agricultural and forestry sector show that fatal accidents with tractors and self-propelled machinery (65–76%) are caused most frequently by roll and runover incidents also in other countries (Erlich et al., 1993; Goodman et al., 1985; Etherton et al., 1991; Gil Coury et al., 1999; CAIR, 2007). The frequency of fatal accidents with tree-point linked, towed and stationary machines is 10–52% worldwide and thus in the range of that in the Austrian agriculture and forestry (Thelin, 2002; Loomis et al., 1997; Horsburgh et al., 2001; Gil Coury et al., 1999; CAIR, 2007). Previous studies also found frequent fatal accidents through PTOs during the operation of three-point linked, towed and stationary machines (Whitman and Field, 1995; Campbell and Field, 1986; Solomon, 2002; Windau, 1998). These are, however, of little importance to the Austrian agriculture anymore because of the activities of safety consultancy services in the past years. For the comparison with other studies it is important to pay attention to country-specific differences in machine types, because different farm machinery and equipment is used in accordance with local business and production types and production conditions.

### 3.2. Worker-specific parameters

Of the victims up to 82.9% (1166/1406) were farm managers (Farmers), 12.7% (178/1406) family members, 3.98% (56/1406) workers and employees and 0.43% (6/1406) other persons. That based on the fact that the most frequently working processes on farms was done by the farm managers (Farmers) themselves in Austria. No details about the affected people were provided by 27.0% (521/1927) of the accident reports. Other characteristics of the injured persons do not emerge from the anonymized accident reports. Workers and employees (83.9%) are significantly more often injured than managers (35.9%) with hand-held machines, family members (37.1%) with self-propelled machines and other persons (50.0%) with three-point linked machines ($p$-value 0.0001). Workers and employees (86.5%), farm managers (Farmers) (72.2%) and other persons (83.3%) sustained mainly light and family members (53.2%) more often severe injuries when involved in accidents ($p$-value 0, 0001). Exclusively farm managers (Farmers) (70.6%) and family members (29.4%) were victims of fatal accidents. Based on the Odds Ratio the risk of suffering a serious injury, during handling or working with agricultural machinery, was 0.65 times higher ([OR] = 0.65, 95% [CI] = 0.44–0.97) for farm managers (Farmers) than for other persons (see Fig. 1).

According to the database results for accident victims, men (88%) over 40 years (68%) with agricultural education (92%) were most frequently affected by an accident. This seems questionable because despite agricultural education a lot of accidents happen with machines. In further agriculture education in Austria the

**Table 1**
Number of accidents after machine category and type (2008–2010) ($n$ = 1927).

| Parameter | Number ($n$) |
|---|---|
| **Machine category**/*-type (total)* | **1927** |
| **Hand-held machines and equipment**<br>*Chain saw > circular saw > hand-held cut off machine > others* | 713 |
| **Three-point linked machines**<br>*Wood splitter > cable winch > front loader > others* | 525 |
| **Self-propelled machines**<br>*Tractor > loader > combine harvester > others* | 414 |
| **Towed machines**<br>*Trailer > slurry tank > timber loader incl. trailer > others* | 218 |
| **Stationary machines**<br>*Helix conveyor > hay crane > belt conveyor* | 57 |

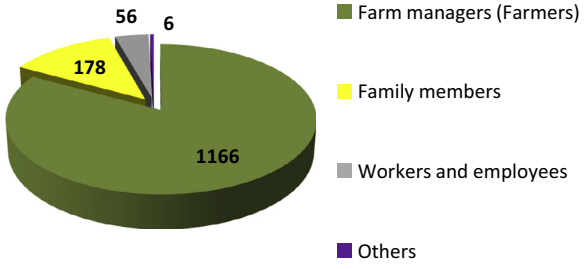


**Fig. 1.** Worker-specific parameters of occupational accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1406).

focus regarding handling and working with machines should be improved. The database results also provided more specific information about the status of the person concerned in the business (gender, age, education, position in the company) than did the accident reports (Kogler et al., 2014*). A comparison and a combination with the results of the ESAW database would provide qualitative value-added information about the injured person.

Results of injury surveys show that only a little more than half of the casualties had participated in induction trainings for proper handling of machines (57.5%, 96/167) and read (53.7%, 94/175) and understood instruction manuals (69.1%, 65/94). Complete workwear was hardly worn (15.8%, 23/146) and physical impairments (hurry, stress, lack of concentration) (44.5%, 89/200) affected the accident. Safety induction training and reading instruction manuals could considerably counteract an accident. When purchasing agricultural machinery second-hand and privately, these induction trainings are hardly ever conducted and the manuals are hardly ever passed on, which is the reason why these accident risks always exist. The difference between the answers given and the total number of 201 injury surveys arises from the fact that not all respondents provided details about each parameter.

For the agricultural and forestry accident situation in other countries it has been documented that farm managers were also frequently victims of fatal accidents albeit less often (50–57%) than in Austria. Workers and employees were more frequently (42–44%) victims of fatal accidents than in Austria (Erlich et al., 1993; Thelin, 2002; Solomon, 2002; Bernhardt and Langley, 1999; Horsburgh et al., 2001). The percentage of fatal accidents of persons aged up to 20 years, who are regarded as family members, was between 10% and 34%, which is similar to the Austrian accident situation (Erlich et al., 1993; Goodman et al., 1985; Murphy et al., 1996; Pickett et al., 1999; Myers et al., 2007). These differences are partly due also to country-specific differences in natural production conditions, farm structures and research questions, which must be considered in the comparative analysis.

### 3.3. Workplace-specific parameters of accident

Of accidents 30.3% (438/1444) occurred in the farmyard area, 23.4% (338/1444) in forestry area, 23.0% (332/1444) in fields and other plots of land, 17.0% (246/1444) in farm buildings and 6.23% (90/1444) in public areas (streets). In 25.1% (483/1927) of the accident reports the details of the accident location were missing (see Fig. 2).

Accidents with self-propelled machines occurred significantly more frequently in fields and on roads (78.9%). Accidents with towed (72.0%), hand-held (52.8%) and stationary (97.8%) machines occurred in the farmyard and farm buildings. For three-pint linked machines, the accident frequency was equally distributed between the farmyard and farm buildings (50.0%) and accident locations outside the farmyards (field and land, forest areas, public areas) ($p$-value 0.0001). Severe injuries occurred significantly more often in the field and other plots of land as well as in forest and in public areas (58.5%). Light injuries occurred in equal parts in the yard and farm buildings (49.4%) and outside the farmyard (50.1%) ($p$-value 0.0045). Fatal accidents were significantly more frequent (83.3%) in the field, plots of land, forest and public areas than in the farmyard and farm buildings (16.3%) ($p$-value 0.009). The Odds Ratio showed an 1.49 times increased risk to suffer a serious injury during handling or working with agricultural machinery in the farmyard ([OR] = 1.49, 95% [CI] = 1:07–2:08) than in other work areas (field and land, forest, public areas).

According to results of the accident database, accidents occurred at a higher rate in farmyards (37.7%), followed by farm buildings (18.6%), forest (18.0%), arable land, meadows and pastures (14.9%) and other agricultural areas (21.1%). There was a very similar quality of information content between accident reports and database. The accident reports provided greater details by given more accurate information about the accident location.

Some of the surveyed victims provided information about adverse environmental factors (26.9%, 54/201) including steep terrain (40.7%, 22/54), slippery and wet soil (9.26%, 5/54), wet and soiled machine parts (27.8%, 15/54), difficult work objects (11.1%, 6/54) and unfavorable work places (dark, dusty, etc.) (11.1%, 11/54) (Quendler et al., 2014).

Similar studies show frequencies of fatal accidents in the field and on plots of land of between 87% and 91%, as they were found for the Austrian agriculture and forestry. Fatal agricultural injuries in public areas (9.0–13%) are less important than in Austria. The frequency of fatal accidents in the field, plots of land and public areas results from the increased number of fatal accidents with self-propelled machines, while roll- and runover accidents and traffic accidents represent frequent accident courses with self-propelled machines worldwide (Goodman et al., 1985; Horsburgh et al., 2001; Gil Coury et al., 1999; Rissanen and Taattola, 2003). Comparative values for fatal accidents in the farmyard of 25% are somewhat higher than the Austrian level (CAIR, 2012), which may be influenced by structural differences and the research design.

### 3.4. Working process and specific task parameters of accident

The most common accident-causing activities across all categories of machines were the direct (machine typical) operation (82.5%, 1541/1867), followed by the coupling and uncoupling of the machine as well as maintenance work (each 7.82%, 146/1867). Other activities (1.23%, 23/1867) and accidents during ascending or descending (0.59%, 11/1867) machines played a minor role. For 3.11% (60/1927) of the accidents, information about the activities that were carried out when the happened was missing (see Fig. 3).

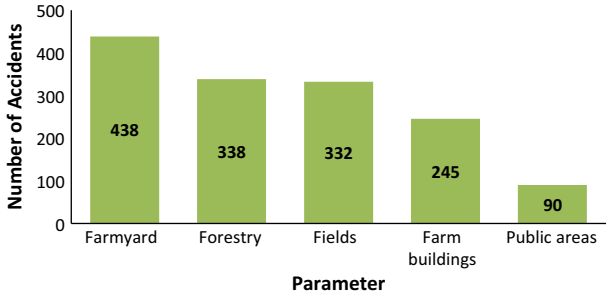


**Fig. 2.** Workplace specific parameters of occupational accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1443).

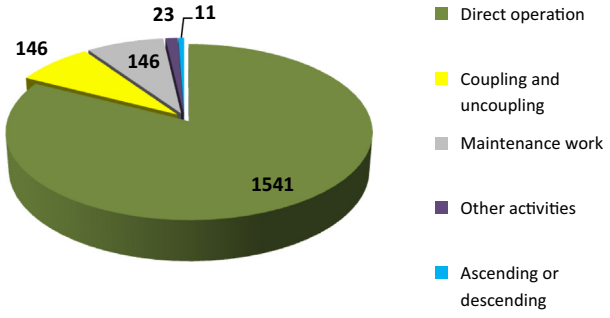


**Fig. 3.** Accident-causing activities of occupational accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1867).

The most common accidents could be observed during coupling and uncoupling (61.4%) and maintenance work (28.1%) on three-point linked machines. Accidents caused by direct operation (41.5%) and by other activities (43.5%) occurred significantly more often with hand-held machines. Accidents during ascending or descending were significantly more common with self-propelled (92.6%) and stationary (43.5%) machines ($p$-value 0.0001). The most common severe (85.4%), light (82.4%) and fatal (85.0%) injuries occurred during direct operation of machines. Further fatal injuries were recorded for the coupling and uncoupling of machinery (15.0%). There exist an increased risk about 1.69 times ([OR] = 1.69, 95% [CI] = 1:19–2:41) to sustain a serious injury during direct operation than during other agricultural work tasks with agricultural machines.

According to the results of the ESAW accident database, accidents occur at a higher rate during agricultural and forestry tillage and harvesting operations (66.8%), followed by maintenance, repair and cleaning work (16.3%), other activities (8.07%), production, handling and processing operations (7.14%), excavation, construction and maintenance work (1.67%) when operating a machine, working with hand tools and operating means of transport. This is generalized information about the work place; information about the actual accident course is only vague. The use of these results from the national ESAW accident database is limited to cross-sector and cross-national generalized comparisons of accident statistics (Kogler et al., 2014*).

According to victims interviewed, problematic work processes included direct operation (machine-specific) (46.8%, 94/201), followed by manually operated machine parts in the course of folding and unfolding of protective covers, quick-change systems and maintenance (e.g. maintenance, cleaning, repair) (23.9%, 48/201) as well as loading and unloading (12.9%, 26/201), coupling and uncoupling of machines (thee-point linked and towed) (9.95%, 20/201), ascending and descending to control and operating stations (2.99%, 6/201) and other activities (3.48%, 7/201) (Quendler et al., 2014).

According to international studies, the most deadly accidents occurred during the direct operation of machinery during agricultural and forestry operations (46–76%). Often these occurred during harvesting operations (grassland, arable, forestry) with different machines (trailed or drawn), as they did in Austria (Goodman et al., 1985; Thelin, 2002; Horsburgh et al., 2001; Pickett et al., 1999; CAIR, 2012). In addition to machines, drowning, falling from elevated work stations, being hit by falling objects and asphyxiation also led to fatalities in the agricultural and forestry sector (CAIR, 2012).

### 3.5. Accident course

The most common accident course was the collision with the machine or machine part (38.8%, 724/1866), closely followed by being caught by moving or rotating machine parts (31.7%, 591/1866). Further accident courses were found to be the roll- and runover with the machine (12.6%, 236/1866), the fall from the machine (11.1%, 207/1866), being hit by an object (5.14%, 96/1866) and traffic accidents (0.64%, 12/1866). In 3.17% (61/1927) of the accident reports, no information about the accident course was given (see Fig. 4).

Accidents with three-point linked (41.5%) and stationary (51.0%) machinery resulted significantly more often from being caught by moving or rotating machine parts. For towed machinery a high rate of accidents occurred by falling from the machine (45.5%). For hand-held machinery, the collision (contact) with the machine (55.2%) and for self-propelled machines the run- and rollover in the field (50.6%) outweighed all other accident courses ($p$-value 0.0001). Being caught by a machine was the significantly more frequent cause of serious injuries (40.7%) and the collision with the machine (50.0%) that of light injuries ($p$-value 0.0001). The fatal injuries occurred significantly more frequent during the run- and rollover of the machine (57.9%), followed by the collision with the machine or machine part (15.8%), being caught by the machine and being hit by objects (each 10.5%) and the fall from the machine (5.26%) ($p$-value 0.0001). The Odds Ratio further showed a 3.23 times increased risk ([OR] = 3.23, 95% [CI] = 2:45–4:27) to suffer a serious injury for being caught during working or handling of agricultural machinery than for any other accident course.

According to the ESAW database, the courses that led to an accident were the loss of control of machinery, transportation and handling equipment and hand tools (69.1%), the fall of a person (15.1%), other movements of the body (11.3%) and other deviations (4.47%). The information content is considerably lower than that of the accident reports, as demonstrated by the above results.

According to the results of the injury survey, missing, worn and improperly constructed steps and ladders (10.9%, 22/201) led to the fall from the machine. Missing, worn and improperly constructed protective covers and folding machine parts (18.9%, 38/201) and insufficient space between the tractor and the machine during coupling and uncoupling (11.9%, 24/201) led to accidents caused by the collision with the machine or machine parts. Machine-specific drive and conveying elements with missing protective covers and shutdown equipment (58.2%, 117/201) led to being caught by the machine (Quendler et al., 2014).

The evaluation of accident (78.5%, 128/163) and new machines (89.6%, 232/259), which were evaluated regarding safety design parameters preventing the collision with the machine or machine parts, showed design deficits in protective covers during the change from transport to operating position, in position holding means for folding machine parts, missing and improperly designed transportation, support devices and quick-change devices and the lack of space between the machine and tractor in approximately 25.1% (32/128) of the accident and 18.4% (43/232) of the new machines evaluated.

The accident (81.0%, 132/163) and new machines (66.4%, 172/259), which were evaluated regarding being caught by running or rotating machine parts, showed a lack of facilities for the operation of dangerous machinery parts with folded protective covers, a lack of protective covers on working tools, a lack of facilities for preventing the operation of machinery during improper handling, difficult-to-use machine parts due to deficiencies in design and manipulation hazards, missing and incorrect versions of additional handrails and a lack of emergency stop devices as detrimental machine designs in 22.8% (30/132) of the accident and 9.20% (16/172) of the new machines evaluated.

Accidents (39.3%, 64/163) and new machines (29.0%, 75/259), which were evaluated for safety design specifications of standards and guidelines relating to the fall from the machine, showed that improper operation and maintenance spaces and the lack of or improper steps and ladders contributed to the accident with 31.1% (20/64) of the accident and 22.7% (17/75) of the new machines evaluated. In addition, 65.6% (107/163) of the accident machines evaluated had no signs or symbols warning of dangerous machine parts and providing instructions for the safe handling of these parts. Such warning signs or symbols were also absent in 23.7% (61/259) of the new machines evaluated.

In other countries, roll- and runover accidents with self-propelled machines caused 34–60% of the fatal accidents. Collision accidents with the machine and machine parts with values between 13% and 18% are similar to the Austrian situation. The number of fatal accidents caused by being hit by objects (13%) and by being caught by the machine (18%) was slightly higher than in Austria (Gil Coury et al., 1999; Erlich et al., 1993; Goodman et al.,

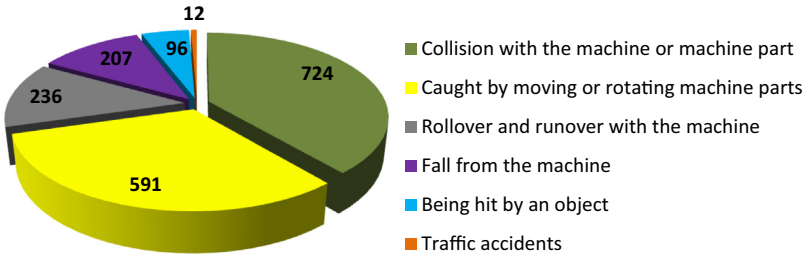


**Fig. 4.** Accident-course of occupational accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1866).

1985; Thelin, 2002; Solomon, 2002). In general, it can be said that the same accident courses as in Austria also lead to serious accidents with and without fatal outcome in the agricultural sector worldwide. Information about the accident-causing human–machine interaction and the conditions of accident machines can rarely be derived from existing data sources. An extension of the accident statistics with an agriculture-specific terminology parameter for the accident course contributes to an improved understanding of the accident-causing human–machine interaction in Austria as well as in world.

### 3.6. Accident cause

The most common causes of occupational accidents with agricultural and forestry machinery were divided into 46.2% (740/1602) human, 39.1% (627/1602) machine, 12.1% (193/1602) environmental and 2.62% (42/1602) other causes of accidents. The human-related causes included the improper handling of equipment, operation and misjudgment as well as slipping, tripping and falling. The machine-related accident causes were mainly missing or improperly constructed machine parts and technical defects. The environmental causes included processed materials (wood, pieces, etc.) and steep terrain, wet and slippery soil conditions. All the information that did not fit into the other categories was classified as other causes of accidents. The severe and light injuries resulted significantly more often from human (44.5%) and mechanical (39.3%) causes of accidents ($p$-value 0.0001). The most common fatal accidents resulted significantly more often from environmental (50.0%), followed by human-related (42.9%) and mechanical (7.14%) accident causes ($p$-value 0.0001) (see Fig. 5).

The most common type of contact according to the ESAW statistics, which broadly describes the cause of accident, was the contact

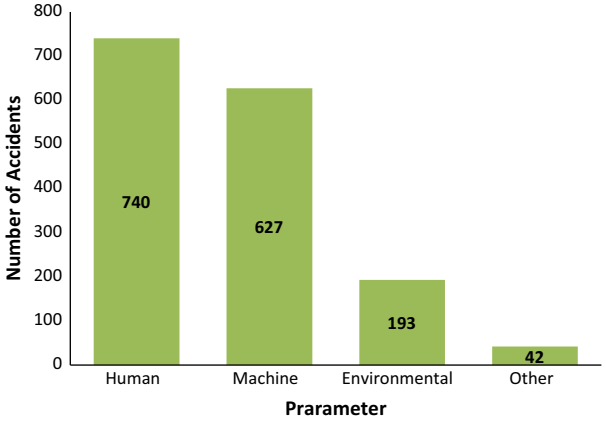


**Fig. 5.** Accident-causes of occupational accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1602).

with pointed and sharp objects (37.1%), followed by vertical and horizontal impacts (22.2%), pinching, trapping between, in and under objects (20.4%), being hit by an object (10.7%) and other contact types (9.64%). A clear differentiation according to environmental, human and machine-related accident causes as done in this study cannot be made from this. Missing values for accident-causing human–machine interaction, in particular machine type, series, model and version of the accident-causing machine part in the database and accident reports, are considered as crucial failings in the determination of the accident circumstances (Quendler et al., 2014).

Construction changes (11.4%, 23/201) and technical defects (3.48%, 7/201) of the accident machines hardly take place. Despite existing wear and construction deficits, due to the age of machines, a large number of accident machines (73.1%, 147/201) are still in use on farms (Quendler et al., 2014). According to comparative studies of fatal accidents, roll- and runover accidents were frequently (50–60%) caused by environmental factors (steep terrain, slopes, slippery and wet soil conditions) and human causes of accidents (driver error, faulty operation, negligence and other physical impairments). Also accidents through being hit by objects caused fatal accidents in the agricultural and forestry sector worldwide, which largely corresponds to the accidents caused by environmental factors in Austria (Gil Coury et al., 1999; Erlich et al., 1993; Goodman et al., 1985; Thelin, 2002; Solomon, 2002; Windau, 1998).

Fatal accidents caused by poor machine conditions, such as wear and missing safety devices, which correspond with the mechanical causes of accidents in Austria, were shown by Mc Gwin et al. (2000). The causes of fatal accidents, which are attributable to human negligence in the Austrian agriculture, include the wearing of too wide clothes, too close crossing of rotating machine parts, oversight of persons in the danger zone, the transport of persons without permissible seat in cabins of tractors and improper operation during forestry work. Comparable studies furnish evidence for fatal accidents caused by being caught by the machine, by removing blockages (50%), too close handling (maintenance, cleaning, services) of running or rotating machine parts (20%) and being trapped between machinery and machine parts (80%) (Goodman et al., 1985; Thelin, 2002; Solomon, 2002; Pickett et al., 1999; Windau, 1998). Thelin (2002), Erlich et al. (1993), Fragar (1996), Murphy et al. (1996) and Schenker (1996) refer to physical and mental impairments such as poor attention, inexperience, aging and severe fatigue as being factors contributing to accidents.

### 3.7. Injuries and affected body parts

The types of injury were differentiated into light and severe injuries. Light injuries (68.4%, 1155/1689) occurred more frequently in accidents with agricultural and forestry machinery and equipment than severe ones. Severe (30.4%, 514/1689) and fatal injuries (1.18%, 20/1689) resulted more rarely. In 12.3% (238/1927) of the accident reports, no details were provided as

to the type of injury. Injured body parts were the head (8.89%, 162/1822), several areas (9.00%, 164/1822), the extremities (73.2%, 1333/1822) and the torso (8.95%, 163/1822). For all machine categories (three-point linked, towed, hand-held, self-propelled and stationary machines) the extremities (73.2%) were significantly more frequently injured than the other areas of the body (26.8%) ($p$-value <0.0001) (see Table 2).

Severe injuries were caused significantly more frequently in multiple areas of the body (47.7%) and in the head region (27.9%). The most common light injuries occurred on arms, hands, legs and feet (62.5%) and the torso (17.6%) ($p$-value <0.0001). Fatal injuries often were injuries involving multiple body areas at the same time ($p$-value <0.0001).

The risk of suffering head injuries and injuries in multiple areas of the body and the torso was 0.13 times higher than the chance of suffering serious injuries of the extremities ([OR] = 0.13, 95% [CI] = 0.073–0.242) during handling and working with agricultural machines.

Employees (92.9%), farm managers (74.6%), family members (58.4%) and other people (100%) tended to sustain injuries of the extremities most often. The injury of multiple body areas played a significant role in the injuries sustained by family members (18.1%). Injuring several body areas (80.3%), the torso (65.1%) and the head (54.6%) occurred significantly more frequently outside the farmyard than in the farmyard. The extremities were injured significantly more often in the farmyard area (54.6%) than outside the farmyard (45.4%) ($p$-value <0.0001). Falling from the machine (45.2%) resulted significantly more often in the injury of several areas of the body. Extremities were significantly more often injured as a result of falling (47.9%), being caught by the machine (87.5%) and colliding with the machine (87.5%). In the other accident courses (46.5%), the head region was affected at a high rate ($p$-value <0.0001).

Human (75.5%), machine (75.3%) and other causes of accidents (80.0%) caused significantly more injuries to the extremities. Accidents which were caused by environmental factors resulted in injuries in several areas (30.8%) at the same time and on the extremities (34.3%) at almost the same rate ($p$-value <0.0001). These results for the type of injury and the affected areas were very similar to those of the ESAW database, which also provided information about treatment and sick leave duration. According to Goodman et al. (1985), Thelin (2002) and Horsburgh et al. (2001), multiple injuries in the head and chest area are increasingly responsible for fatal accidents in the agricultural sector, as they are in Austria. As in Austria, diverse body regions were affected by light and serious injuries conditioned by the diversity, design differences and deficits of agricultural machinery.

### 3.8. Safety deficits

Safety deficiencies are not listed in the Austrian accident reports. These were derived from the information on the parameters of the accident reports. The classification was carried out in the accident factors human, machine, environment and the combination of human, machine and environment. Safety deficits of all machine groups were most commonly caused by human errors (55.2%, 1001/1814) and the combination of human, machine and environmental factors (21.6%, 391/1814). Both mechanical (13.5%, 244/1814) and environmental safety defects (9.81%, 178/1814) constituted a minor role. For 5.86% (113/1927) of the accidents, safety deficits could not be derived due to missing data regarding accident course and cause in the accident reports (see Fig. 6).

The human-related safety deficiencies included improper operation or failure to use additional work tools or equipment, not wearing protective clothing and a lack of driving experience and misjudgment of the terrain, ground and machine conditions. Machine-related safety deficiencies included construction defects and deficits, signs of wear and tear and technical problems. Environmental safety deficiencies were unfavorable ground conditions (wet, slippery, etc.), adverse workstations (darkness, dust, noise, odor, etc.) as well as unfavorable topographical features. The combination of human, machine and environmental safety deficits was chosen for those deficits that could not be allocated to one specific category because of missing information in the accident reports.

Human safety-related deficits occurred with towed (53.7%), hand-held (85.9%) and self-propelled machinery (37.3%) significantly more often than those related to machine, environment or a combination of human, machine and the environment factors. Three-point linked (33.4%) and stationary (45.3%) machines had significantly more frequent types of machinery safety deficiencies that were related to the combination of human, machine and the environment. For three-point linked machines (33.2%) the machine-related deficits and for stationary machines (43.4%) the human safety-related deficits followed the safety deficits of the combination of human, machine and the environmental factors. Regarding self-propelled machines, the environmental factors (31.5%) could be identified as the second most frequent security risk ($p$-value <0.0001).

The extremities were significantly more often injured through human (81.5%), machine (80.8%) and the combination of human, machine and environmental safety deficits (67.1%) than the other areas of the body (head, several areas, torso). Injuries that were caused by environmental safety deficits affected significantly more often several body parts (33.5%) ($p$-value <0.0001). Severe (46.4%) and light (61.1%) injuries resulted significantly more often from human safety deficits ($p$-value <0.0001). A large number of fatal accidents were caused by environmental factors (50.0%), followed by human (35.7%) and machine (14.3%) safety deficits ($p$-value < 0.0001). The risk of sustaining serious injuries through safety deficits composed of a combination of human, machine and environment factors was 0.67 times higher ([OR] = 0.67, 95% [CI] = 0.51–0.89) compared to the human safety deficit.

**Table 2**
Injury type and affected body parts by accidents with machinery in the Austrian agriculture and forestry (2008–2010).

| Parameter | Number ($n$) |
|---|---|
| Injury types (total) | 1689 |
| Light | 1155 |
| Severe | 514 |
| Fatal | 20 |
| Body parts (total) | 1822 |
| Extremities | 1333 |
| Several areas | 164 |
| Head | 162 |
| Torso | 163 |

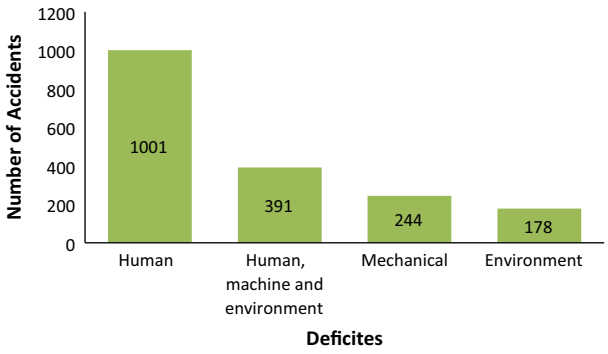


**Fig. 6.** Safety deficits by accidents with machinery in the Austrian agriculture and forestry 2008–2010 ($n$ = 1814).

Studies of fatal agricultural accidents furnish evidence in a broader sense frequently for human and environmental safety deficits, whereby rollover accidents with tractors and forestry accidents occur most frequently due to improper handling and unfavorable environmental conditions, and accidents caused by being runover and being caught by machine parts due to incorrect operation and improper handling of the operator (Erlich et al., 1993; Goodman et al., 1985; Etherton et al., 1991; Gil Coury et al., 1999; Thelin, 2002; Solomon, 2002; Pickett et al., 1999). Safety deficits emerge from accident studies only to a limited degree. They can be partially derived only by parameters such as course and cause of accidents.

### 3.9. Prevention measures

To achieve the main aim of the accident analysis, the derivation of prevention measures that meet the demand, the information on the respective parameters in the database and in the accident reports was not sufficient. A combined analysis of the accident reports and ESAW database significantly improved the information about the accidents in order to develop sustainable prevention measures. The modification of the standard forms for accidents reports, in particular the addition of machine-related parameters (brand, series, type and version of the accident-causing machine part) and a pictorial record can substantially improve the information quality of Austrian accident reports. Particularly the additional injury surveys and machine evaluations used to clarify the accident-causing human–machine interaction could considerably reduce the number of accidents.

Constructive suggestions for technical facilities to avoid accident situations were mentioned by only a few accident victims (34.8%, 70/201). These referred to enhanced and additional steps and ladders (14.3%, 10/70) to reach operating and maintenance positions, protective guards and covers (38.6%, 27/70) as well as the improved design of machine-specific working tools (22.9%, 16/70), controls and drive devices (12.9%, 9/70) and coupling devices for towed and three-point linked machines (11.4%, 8/70). Only three-quarter of the injured persons (77.6%, 156/201) mentioned suggestions to avoid the accident situation afterwards. These referred to a secure and more focused working technique (85.9%, 134/156), the use of additional working tools (8.33%, 13/156), improved design of machines (3.21%, 5/156) and the wearing of workwear (2.56%, 4/156). The majority (72.1%, 145/201) of the casualties changed their workplace and work technique after an accident.

Existing technical preventive measures that could be derived for accident and new machines, from the accident reports in combination with the results from the database, were standard-compliant steps and ladders as standard instead of optional equipment for self-propelled, towed and selected three-point linked machines to prevent the fall from the machine. A revision of the standards for steps and ladders in size and design (size, width, slip resistance, slope, handrails, grab bars, hole dimensions for self-cleaning, assembly) and an enhanced implementation in agricultural and forestry machinery can help to avoid accidents caused by falling from machine.

Accidents caused by being caught by running or rotating machine parts could be avoided by implementing electronic systems that shut off moving machine parts after leaving the driver's seat as well as when coming too close to these machine parts and when opening protective covers (Schrempp et al., 2013). Other prevention measures are the proper condition of protective covers, machine markings (pictograms and warnings) and available emergency stop systems (personal communication). People detection systems (infrared or cameras), which are currently being developed, can achieve a shutdown of self-propelled and remotely controlled machines in the presence of persons in the danger zone (Bruckmann et al., 2012).

To avoid rollover accidents due to steep terrain, design measures (ROPS, FOPS, closed security cabins including seat belt) (Mayrhofer et al., 2014; Springfeldt, 1996; Springfeldt et al., 1998), additional machinery equipment (weight, ground and tilt sensors including warning indicators and signals (Stempfhuber, 2004; Demmel et al., 2002; Könnecke, 2007; Brunotte, 2011; Nichol et al., 2005; Özdes et al., 2011; Cobo, 2012)) and awareness-building measures (warnings, ballasting of the machine, twin tires, low center of gravity, tyre tread, advisory discussion during a new purchase) in combination with schooling and training measures (safety training, handling, assessment of terrain and ground conditions) have been suggested (Mayrhofer et al., 2014; Nichol et al., 2005; Huber, 2010; Jaarsma and De Vries, 2012).

Accidents caused by the collision with the machine can be avoided by implementing people detection systems (infrared, RFID, cameras, sensors) (Sick, 2008), quick coupling systems when coupling and uncoupling of devices, integrated check fuses for hand-held machines and proper position holding means for folding machine parts on the one hand. Constructively sound and intact personal protection equipment, avoidance of persons in the danger zone, proper operation and use of additional working tools (Personal Communication) can counteract accident situations on the other hand.

Prevention measures mentioned in existing studies are related to technical measures which include the design of machinery parts and equipment by revising the appropriate standards and guidelines taking into account the opinions of users, safety consultants and designers. Furthermore, constructional adjustments to machinery according to age groups to increase their capacity to prevent accidents of older persons may be helpful. These include safety cabs for tractors including seat belts and devices which prevent being caught by rotating machine parts (PTO) when people get too close to them. Recommended prevention measures raising awareness of existing risks on farms include technical training, driver safety training and improved work organization. Prevention suggestions frequently consist of a combination of technical, organizational and training measures which are attributed the highest quality to avoid accidents (Akdur et al., 2010; Erlich et al., 1993; Goodman et al., 1985; Thelin, 2002; Cameron and Bishop, 1992; Solomon, 2002; Etherton et al., 1991; Bernhardt and Langley, 1999; Pickett et al., 1999; Lee et al., 2012; Gil Coury et al., 1999).

To achieve the highest quality level of the accident analysis to identify the accident-causing human–machine interaction, results from the ESAW database and accident reports must be expanded by including the results of injury surveys and machine evaluations. In the course of these surveys, accident factors must be distinguished as to their causes, environmental, human and machine related, or a combination thereof in order to derive efficient sustainable prevention measures. The additional evaluation of new machines including manufacturer survey to obtain information about design differences, deficits, failures, weaknesses and technical innovations significantly facilitates the derivation of prevention measures for accident and new machines.

## 4. Summary

Agricultural and forestry businesses in Austria are characterized by their diversity in the natural production conditions and by a high intrinsic level of mechanization. The number of serious and partially fatal accidents at work, arising in the course of various agricultural activities, is still very high. The accident scenarios in which people suffer injuries are very diverse despite ever improving technology, coordinated prevention measures and better education of people. Accidents occur through a number of various

combinations of activities, accident courses and causes, different machines and equipment in agriculture and forestry. Documented accident reports of recognized occupational accidents with agricultural and forestry machinery and equipment in the Austrian agriculture and forestry for the period 2008–2010 form the data basis. These reports were evaluated descriptively and analytically using the chi-square test method and the Odds Ratio analysis.

Predominantly farm managers and family members were injured during the direct operation of hand-held and three-point linked machines in the farmyard and in field and forest areas through the collision with and by being caught by the machine or machine parts. Human causes of accidents caused more injuries to the upper and lower extremities. Fatal accidents occurred significantly more often with self-propelled machines during direct operation in the field and plots of land, in forest areas and in public areas because of rollover incidents due to unfavorable environmental conditions in combination with improper handling. Severe injuries occurred significantly more often with attached machines because of being caught by the machine or its parts due to human causes and deficits during direct operation in the field and plots of land, in forests and public areas. Severe injuries mainly related to several areas of the body; mainly family members were affected.

For farm managers an increased risk of suffering a serious injury in the farmyard consisted in being caught by the machine or machine parts due to a combination of human, machine and environmental safety deficiencies during the direct operation of three-point linked machines. The high proportion of not reading and understanding operating instructions, missing workwear, existing physical impairments (hurry, stress, lack of concentration), adverse environmental factors, improper operation and handling, as well as difficult-to-use and improperly designed machine parts seemed to influence the occurrence of accidents.

## 5. Conclusion

Studies in other countries show similar trends in the collected parameters; the results differ according to differences in production conditions, farm structures and research questions. The causes of accidents and the accident-causing agricultural and forestry operation, in particular the specific accident-causing human–machine interaction, were not always clear from the results of the variables of the accident reports. Information deficits were offset by interviewing casualties and the evaluation of new and accident machines in accordance with applicable guidelines and standards, which enabled the derivation of sustainable prevention measures that meet the demand.

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## *Supplements*

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