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• *Water resources – Agricultural water management – Brandenburg, Germany*

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Agricultural Water Management in Brandenburg

Wassermanagement in der Landwirtschaft in Brandenburg

With 3 Figures, 7 Tables and 1 Photo

The present study explores whether regional water resources can be used more efficiently by Brandenburg's farming systems. A description of agriculture in Brandenburg today is followed by a systematic analysis of measures to raise the water efficiency. Brandenburg's agricultural systems are divided into three sections: soil, plant production and livestock farming. Within these sections measures to increase water efficiency are listed and analysed with reference to five objective criteria for raising water use efficiency. In view of the complexity of farming systems in Brandenburg, general measures to raise water use efficiency could not be derived. Site-specific tillage practices and crop patterns adjusted to recent weather conditions may reflect the specific diversity of Brandenburg more efficiently.

1. Introduction

All over the world, the most important production factors in agriculture are soil and water. With worldwide climate change and population growth, changes in livestock and crop farming, and the increasingly strained regional water balance, enormous challenges have to be faced in the agricultural sector in Brandenburg. These problems necessitate further investigations into the possibility of improving water use efficiency in farming. With their sandy soils and resulting low water-storage capacity, local sites lose their productivity if they are subjected to more frequent and long-lasting droughts without the use of irrigation. In livestock husbandry an expected rise in temperature will lead to higher standards in temperature regulation of animal housing and higher demand for drinking water. To maintain and develop the competitiveness and sustainability of agriculture in Brandenburg, it is necessary to deal thoroughly with the three sections of soil, plant production and livestock breeding.

In this study a systematic approach has been chosen. Water management is presented, and chanc-

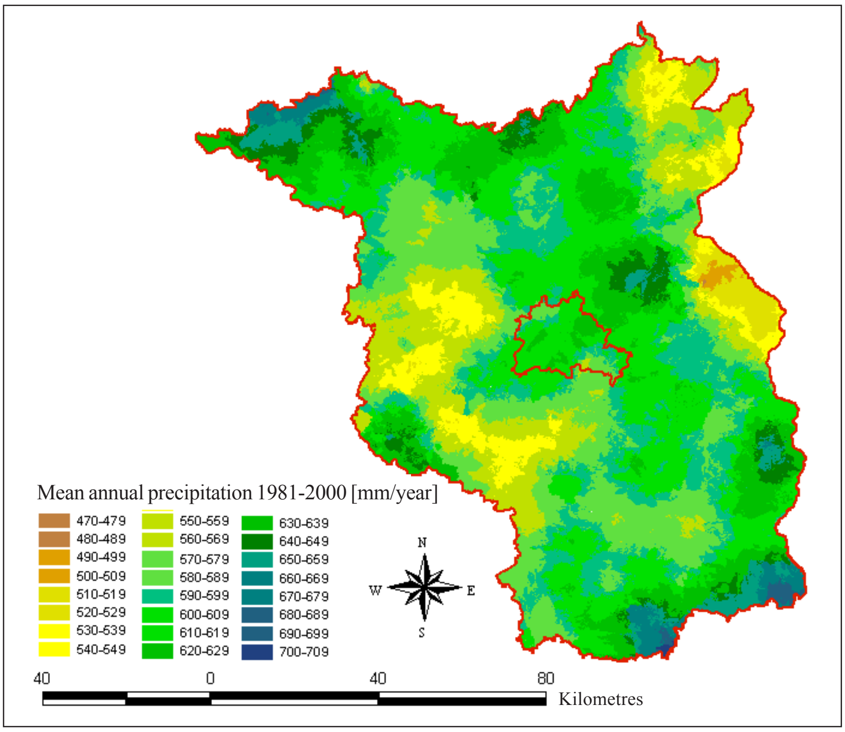

Fig. 1 Corrected mean annual precipitation, 1981-2000, in Brandenburg and Berlin (modified after LUA 2005, data source: German Weather Service DWD) / *Korrigierter durchschnittlicher jährlicher Niederschlag 1981-2000 in Brandenburg und Berlin (verändert nach LUA 2005, Datenquelle: Deutscher Wetterdienst DWD)*

es and possibilities of improving water use efficiency are discussed and listed systematically.

2. Climate, Hydrology and Soils in Brandenburg

Brandenburg lies in the temperate, continental climate zone with mean annual temperatures between 7.8°C and 9.5°C (LUA 2005). Aside from the west-east gradation of the Atlantic climate impact, the differences in height above sea level affect the regional distribution of precipitation (see *Fig. 1*). Slightly more precipitation falls in summer than in winter. Owing to the low level of annual precipitation, Brandenburg and Berlin rank among the driest regions in Germany and Europe (MLUV 2009b, *Köstner* et al. 2007). Numerous groundwater observation gauges show slightly depleting groundwater table levels.

Trend analyses have indicated a significant decrease of percolation especially for areas with a shallow groundwater table already in the period 1961-1998 (*Lahmer* 2004). There is no sign for a general anthropogenic origin of the depleting groundwater table. Only in some cases direct anthropogenic influences are to be seen, e.g. *Gerstengarbe* et al. (2003) stated that the depleting groundwater tables were caused by the abandonment of the large sewage fields near Berlin after 1970. The natural fluctuation of the groundwater level lies with-

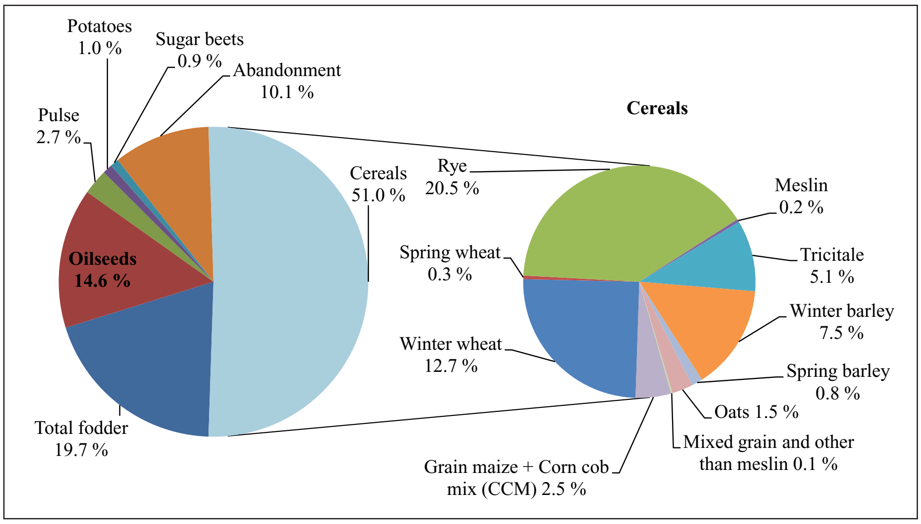

Fig. 2 Share of the respective crops on the arable land in Brandenburg. Data source: government reports on agriculture, *Agrarbericht* 2008 (MLUV 2009) / *Anteil der jeweiligen Fruchtarten am Gesamtackerland (2007). Daten: Agrarbericht 2008 (MLUV 2009)*

in the variation of the percolation rate, which depends on several parameters like precipitation, groundwater level, soil type and temperature. For the investigation of the most probable reasons and the assessment of the development of the percolation rate in Brandenburg *Lahmer* and *Pfützner* (2003) used a high-resolution precipitation-runoff model. Their modelling approaches resulted in the statement that the increase of the mean daily temperature by about 1°C turned out to be statistically significant. Furthermore they stated that 75 % of the total area of Brandenburg show a decrease in percolation and for almost 5 % of the area this decrease is statistically significant.

Considering different scenarios suggested by IPCC, regional simulation models resulted in a trend towards rising temperatures in Brandenburg during the next 50 years (e.g. *Gerstengarbe* et al. 2003). This rise in temperature leads to an acceleration of the water cycle, with higher evaporation, and an extension of the growing season. Yet the modelling of the precipitation is still affected by great uncertainties.

Predominately sandy or loamy-sandy soils with low contents of organic matter in the topsoil and resulting low storage capacities are characteristic for the state of Brandenburg; the soils have an unfavourable water regime. The mostly sandy texture in the main rooting zone can only store around 80 mm of plant available water. Considering that the precipitation is only 250 mm during the vegetation period, the soil water reserves are insufficient for high yields. In comparison with other German locations it can be seen that places with sandy soils, e.g. Dülmen (North Rhine-Westphalia), have a higher annual precipitation of 900 mm compensating the low storage capacity of the soils. Other locations, e.g. in the federal state of Saxony-Anhalt, have a comparably low annual precipitation of 500 mm; but here a chernozem is the typical soil, with a storage capacity of 500 mm in the main rooting zone. This large value compensates the low precipitation.

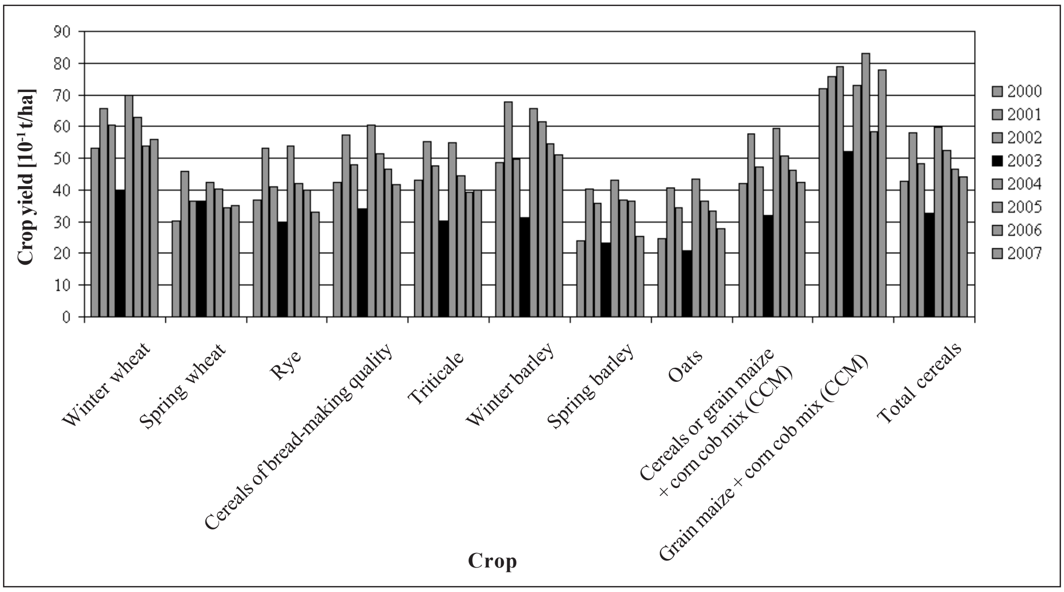

Fig. 3 Cereal crop yields in Brandenburg between 2000 and 2007 (data source: Government reports on agriculture (*Agrarberichte*) 2001-2007, *MLUV 2002-2008*) / *Getreideerträge in Brandenburg von 2000 bis 2007. Daten: Agrarberichte 2001 bis 2007 (MLUV 2002-2008)*

The production factors in Brandenburg show an extreme low annual precipitation amount combined with low storage capacities of the soils in comparison to the rest of Germany.

3. Agriculture in Brandenburg

The crop yields in Brandenburg are noticeably below the federal average. Currently, about 1,330 thousand hectares (tha), representing approximately 45 % of the entire area of Brandenburg, are used for farming, of which 78 % is arable land and 22 % grassland (MLUV 2009). Mostly commercial crops are grown. Cereals are cultivated on roughly one half of the arable land (see *Fig. 2*). Because of the poor soils, periodic droughts and the frost hazard, rye is the main cereal crop planted. Silage maize (120 tha) was the dominant forage crop (total of 200 tha) in 2007, reaching the highest level within the last 17 years.

The low level of agricultural production in Brandenburg compared with the federal average suffered a further reduction in 2003 (*Fig. 3*). In parts, crop failure was considerable, due to a period of strong frosts in winter and spring and a long-lasting drought in early summer with precipitation deficits of 40 % to 70 % from April to July (Statistik Berlin-Brandenburg 2007).

In Brandenburg, 573,000 cattle were kept in 2007, of which 165,100 were dairy cows and 95,000 suckler cows and nurse cows. Compared with 1999, the number of cattle decreased by 15 %. Pig keeping increased by 7 % from 1999 to 2007, with 820,000 pigs in 2007. The number of brood sows rose just slightly up to 100,000. Sheep breeding has shrunk by about one quarter since 1999. In contrast, poultry farming gained greatly in importance within this period. In 2007 nearly 8.5 million (M) birds were kept, including 2.5 M laying hens and

Tab. 1 Compilation of measures to increase the efficiency of water use and to reduce the amount of process water within three analysed sections / *Übersicht über Maßnahmen zur Steigerung der Wassereffizienz und Verminderung des benötigten Prozesswassers innerhalb der drei Teilbereiche*

Soil	Plant production	Livestock breeding
Soil tillage • Roughening of the surface/ fallowing of crusts • Seed-bed preparation **Humus conservation** • Application of organic matter • Mulching • Turning under of crop residues	**Cultivation** • Drought-tolerant varieties • Varieties with high transpiration efficiency **Seeding** • High crop density • Consideration of the current vegetative period **Fertilising** • Sufficient potassium supply • Support of root formation **Optimising of crop rotation and intermediate crop** **Avoiding competition by plant protection** **Water-saving irrigation** • Selection of efficient irrigation techniques • Precision irrigation **Water-saving storage and cleaning of field crops by circuitry of the water**	**Reduction of drinking water consumption** • Maintenance at regular intervals • Dimensioning of drinking water installation **Increase in water use efficiency of cleaning processes** • Soaking • Use of broom for cleaning • Separate collecting, storing and applying of milk house and milking house waste water **Increase in water use efficiency of cooling processes** • Circuitry of cooling water • Productive use of cooling water • Cooling by spray humidification only up to a certain atmospheric humidity (< 60 %) • Appropriate nozzles and valves **Reduction of water-based processes**

3.2 M poulards. In 1999 only approximately 7 M birds were kept (MLUV 2009).

In Brandenburg, 7.5 Mm³ water were used for irrigation on a small area of 1 % of the utilised agricultural area in 2002. The demand for irrigation water increased by 180 % in the period from 1998 to 2004 (Statistik Berlin-Brandenburg 2004). It is expected that this tendency will continue.

4. Catalogue of Measures

The following measures were analysed to present possible improvements in the field of water management within the 'farming system' by raising the efficiency of water use (see *Tab. 1*).

Water use efficiency is used as a target parameter in the context of yield improvement respectively improvement of water productivity

Tab. 2 Evaluation of the measures presented with regard to their impacts on the soil system: + positive impact on
Bewertung der vorgestellten Maßnahmen der Expertise nach ihren Wirkungsweisen im Bereich Boden:

Soil	**Increase of transpiration efficiency**	**Seasonal or spatial increase of the water reservoir**
Roughening of the surface / fallowing of crusts	+ Intense root formation is encouraged by soil loosening	Low pore volumes by compaction of the soil (traditional tillage) + Increase in root penetration
Seed-bed preparation	- Increase of transpiration by reducing wind speed	- Low pore volumes by compaction of the soil depending on the number of tractor drives + Water storage within the organic matter
Application of organic matter	+ Intense root formation is encouraged by soil loosening	+ Water storage within the organic matter + Higher pore volumes by soil loosening + Increase in root penetration
Mulching (direct drilling)	- Retarded growth by reduction of soil temperature	+ Water storage within the mulch cover
Turning under of crop residues	O	+ Water storage within the organic matter

or 'more crop per drop'. This study looks at impact of measures on the following five target parameters according to *Bouman* (2007) and *Amede* et al. (2009), all of which serve to increase water use efficiency.

(1) Increase of the transpiration efficiency: With increased production of dry matter or harvest product in relation to the water used, the transpiration efficiency is raised. Avoiding competition by applying plant protectants may help to increase the transpiration efficiency. Also breeding measures, fertilisation and optimised timing of the blooming period may raise the transpiration efficiency.

(2) Seasonal or spatial increase of the water reservoir: A plant is provided with a potentially larger water reservoir. For example humus is able to store 3-5 times its own weight in water. Higher humus concentrations increase the potential water storage in the soil. With a pronounced, extensive root mat, the plant has access to water resources further away. A good timing of seeding and the following growing period enables the plants to use the water resources optimally, i.e. at the time of specific demand. Breeding focused on varieties that ripen fast and are therefore not exposed to summer droughts and heat is becoming more important.

the corresponding target parameter, – negative impact on the corresponding target parameter, o no effect
+ *positiver Effekt auf die entsprechende Zielgröße, – negativer Effekt auf die entsprechende Zielgröße,* o *kein Effekt*

Increase of non-irrigative proportion of water reservoir	**Decrease of non-transpirative water losses**	**Economising on process water and drinking water**
+ Increase of infiltration + Preservation of residual soil moisture	+ Reduction of evaporation by intersecting the capillary in the topsoil (conservation tillage) - Increase of evaporation from the soil by capillary rise (traditional tillage)	O
+ Storage of precipitation water by reducing wind speed	+ Avoiding competition by mechanical weed destruction + Reduction of soil evaporation via dense and regular growth + Reduction of soil evaporation by reducing wind speed	O
+ Reduction of high percolation rates	- Increase of soil evaporation because of higher heat absorption due to the dark colour of the humus	O
- Low precipitation is intercepted and evaporates	+ Reduction of evaporation by intersecting the capillary in the topsoil + Reduction of soil temperature	O
O	O	O

(3) Increase of green-water components of the water resources: Green water is kept in the soil or in an artificial reservoir and can be used at a later date. Storing precipitation water or soil water, e.g. in a fallow, raises the green-water fraction of the water reservoir.

(4) Decrease of non-transpirative water losses: Unproductive transpiration of e.g. soil water or weeds which does not contribute to the production of dry matter by the crop has to be avoided. Application of plant protectants prevents competition by weeds. Surface water runoff is also an unproductive water loss. A fast-growing and dense plant cover helps reduce the evaporation from the soil. The latter is not necessarily termed unproductive transpiration, as evapotranspiration can have a significant cooling effect on the plants. At high temperatures and strong insolation, the cooling effect by evapotranspiration can become a critical factor.

(5) Economising on process water and drinking water: In the 'farming system' process water is needed during the treatment of harvest products and in livestock farming. Water can be saved via recycling of the water used for evaporative cooling of animal housing. By eliminating leakages from the drinking water installations, water losses may be reduced.

Tab. 3 Presentation of three methods of different tillage intensities
Darstellung von drei Verfahren mit unterschiedlicher Bodenbearbeitungsintensität

Method	**Traditional tillage**	**Conservation tillage**	**Direct drilling**
Process	Plough	Grubber	Direct drill
Intensity of soil tillage	High	Medium	Low
Impact on humus concentration	Wasting	Preservative	Preservative
Impact on water balance	• Lower pore volume due to compaction of soils • Increase in infiltration • Increase in evaporation from soil due to capillary rise	• Cutting off the capillary in the top soil and reducing evaporation from the soil • Increase in storage capacity due to humus preservation	• Decrease in evaporation • Absorption of air moisture within mulch cover • Increase in storage capacity due to humus preservation

4.1 Soil

Several measures can be taken in agricultural land use to increase water use efficiency. According to their effects, the measures analysed are classified into the five target parameters, all of which serve to increase water use efficiency (see *Tab. 2*).

4.1.1. Soil tillage

If the **surface is roughened and the crusts have been fallowed**, precipitation water can infiltrate more easily. Stubble cleaning with a plough helps preserve residual moisture, initiates rotting of plant residues, weeds mechanically, turns under fertilizer or lime, and improves the workability and friability of the soil. On sandy soils weeding and preservation of residual moisture are a major concern. This measure increases the green-water fraction of the water reservoir.

Depending on the intensity of the cultivation operation (see *Tab. 3*), either the capillary in the top soil is cut off, intercepting the capillary rise and reducing evaporation from the soil (as in the case of conservation tillage), or soil evaporation is increased (as in the case of traditional, intensive tillage). Loosening of the soil encourages intensive root penetration and therefore increases the spatial water reservoir and the transpiration efficiency.

Proper **seed-bed preparation** encourages dense and regular leaf growth, leading to a reduction of non-transpirative water losses. For relevant seed-bed parameters, crop-specific standards exist for density and aggregate size distribution in the seed-bed. An adequate combination of implements produces a better working effect and reduces the number of runs. Tractor-induced compaction can reduce the water conductivity, especially of sandy soils. Decreasing wind speeds can be achieved by e.g. ploughing perpendicular to the wind direction, which in turn reduces evapotranspiration and non-transpirative water losses and preserves green water in the soil.

Basic tillage can be separated into three different methods: traditional tillage, conservation tillage and direct drilling without any tillage (*Köller* and *Linke* 2001; see *Tab. 3*). Ploughing turns crop residues under deep into the ground, while with the other two methods (grubber, direct drilling) the plant residues remain close to the surface.

Traditional tillage is targeted at an increased infiltration, but at the same time an increase in evaporation from the soil and a compaction of the soil can be observed. The depth and intensity of the tractor-induced compaction depend on soil moisture, soil type, pressure and hub load of the farm machine. Soil structure is affected by shallow conservation tillage following the grain harvest, as well as by hoeing crops with broad row-spacing and late canopy closure. *Ellmer* et al. (2001) report results from comparing two tillage rotation systems on medium silty sandy soil in Blumberg (Barnim district). On the site investigated, maize and potatoes can be easily cultivated after no-plough tillage. Grubbing once or twice and catch cropping as mulch can ensure satisfactory soil structure conditions, even after perennial no-plough tillage. Grain, in contrast, shows a distinctly reduced yield after grass-clover used for greening of fallow land or as forage plant. In the first year, crop yields after direct drilling and traditional seed furrow are the same. After three years, even robust rye cannot compensate the still deteriorating soil conditions. The authors suggest adjusting soil tillage systems to the crop rotation (see *Tab. 4*).

On silty sandy soils with a low structure stability, temporary no-plough tillage may be successfully integrated into the crop rotation. Continuous no-plough tillage is not feasible.

Tab. 4 Example of a tillage rotation system on medium silty-sandy soil (*Ellmer* et al. 2001) / *Beispiel für eine Bodenbearbeitungsfolge auf mittelschluffigem Sandboden (Ellmer et al. 2001)*

Crop rotation	Soil tillage rotation system
Maize silage	↓
	Mulch seeding or direct drilling
Winter wheat	↓
	Plough, seed furrow 15 to 20 cm Drill seeding
Winter barley	↓
	Non-turning loosening, 15 cm Freezing-off of summer catch crop Mulch seeding with seed-bed preparation
Peas	↓
	If necessary, shallow loosening tillage Mulch seeding or direct drilling
Winter wheat	↓
	Non-turning loosening, 15 cm Freezing-off of summer catch crop Mulch seeding
Maize silage	↓

4.1.2 Humus conservation

Application of organic matter results in spatial enlargement of the water reservoir and reduction of soil density. These conditions enable strong root formation (*Li* et al. 2009) which in turn adds to a larger water reservoir. Furthermore, the organic matter reduces the high percolation rate in sandy soils (*Withers* and *Vipond* 1978) which leads to an increase of the green-water portion of the water reservoir. Because of the dark colour of the humus, the heat absorption of the soil is increased and the soil temperatures are higher. This may result in higher non-transpirative water losses.

Humus accumulation by applying organic fertilisers has no lasting effect on the light sandy soils in Brandenburg. There are soil-specific ranges of humus concentration for different soil types. The humus concentration can be raised only within specific boundaries. In sandy soils, the humus concentration of the topsoil or of the continuously tilled horizon is

Tab. 5 Evaluation of the measures presented with regard to their impacts on the plants system: + positive impact on the
vorgestellten Maßnahmen der Expertise nach ihren Wirkungsweisen im Bereich der Pflanzenproduktion:

Plant production	**Increase of transpiration coefficients**	**Seasonal or spatial increase of the water reservoir**
Breeding for optimised timing	+ Timing by breeding of varieties with optimised blooming and fruiting period + High transpiration coefficient	O
Breeding of drought-tolerant varieties	+ Timing + High transpiration coefficient	O
High crop density by proper sowing	O	O
Consideration of the current vegetative period when sowing	+ Timing	O
Sufficient potassium supply	+ High transpiration coefficient + Intense root formation is encouraged	+ Increase in root penetration
Support of root formation by fertilisation	+ Intense root formation is encouraged	+ Increase in root penetration
Optimising of crop rotation and intermediate crop	+ Varieties with high transpiration coefficient	+ By avoiding competition + High root penetration of previous crop encourages intense root formation of the follower crop + Water storage within organic matter produced by humus accumulation - Little organic matter caused by humus decomposition
Plant protection	+ Avoiding competition	O
Precision irrigation	+ Relative high transpiration coefficient	O

as low as 1.4 to 2 % (*Kundler* 1989). Higher humus concentrations are typical of clayey soils, moist or wet soils and soils in high-rainfall climates. Strongly ventilated, sandy soils generally show low humus concentrations.

Mulching decreases evaporation from the soil by reducing soil temperature, avoiding transfer of air moisture, absorbing air moisture within the mulch cover and reducing wind speeds at the soil/atmosphere boundary (*Greb* 1966). Mulching reduces non-transpirative water losses. Storage of precipitation water within the mulch cover may result in spatial enlargement of the water reservoir. Direct drilling into the mulch cover may keep soil temperatures lower than they are after conservation tillage. A slower rise in soil temperatures can be observed after less intensive tillage. Reducing soil temperatures may slow down the growth of corresponding target parameter, – negative impact on the corresponding target parameter, o no effect / *Bewertung der + positiver Effekt auf die entsprechende Zielgröße, – negativer Effekt auf die entsprechende Zielgröße,* o *kein Effekt*

Increase of non-irrigative proportion of water reservoir	**Decrease of non-transpirative water losses**	**Economizing on process water and drinking water**
O	O	O
O	O	O
O	+ High crop density	O
O	O	O
O	+ High crop density	O
O	+ High crop density	O
O	+ High crop density + Large-leaved plants	O
O	+ Avoiding competition	O
- Withdrawal of groundwater, surface water or bank filtrate for irrigation + Use-saved precipitation water	O	+ Deficit irrigation

the field crop. All in all, the temperature curve is more even with direct drilling.

To a certain extent, however, mulching on the light sandy soils of Brandenburg shows only little effect. Applying 20-25 t straw/ha in Thyrow (Teltow-Fläming district) resulted in a mulch cover of just 1-2 cm thickness after one year (see *Photo 1*, right). Precipitation is intercepted by the mulch cover and evaporates directly again. This can be observed with precipitation of low average intensity of < 10 mm. In this case infiltration is reduced due to water losses by interception or water intake of the mulch cover.

With regard to the turning under of crop residues, harvest residues have an impact on the energy exchange between soil surface and atmosphere, due to the albedo, the aerodynamic coefficient and the exchange of air moisture. Har-

Photo 1 Comparison between plough seeding/seeding after non-turning loosening (left photo, in the background: vital plants) and direct drilling (left photo in the foreground and right photo: poor plants) of maize in Thyrow (Teltow-Fläming; Photos *Drastig,* ATB*) / Vergleich zwischen Pflugsaat bzw. Saat nach nicht wendender Bodenbearbeitung (linkes Bild im Hintergrund: vitale Pflanze) und Direktsaat (linkes Bild im Vordergrund, rechtes Bild: kümmerliche Pflanzen) von Mais, Standort Thyrow (Teltow-Fläming; Photos: Drastig, ATB)*

vest residues may preserve residual soil moisture and increase the seasonal water reservoir.

4.2 Plant production

According to their effects, the measures investigated are classified into five target parameters (see *Tab. 5*).

4.2.1 Plant breeding

To improve water use efficiency, plant breeding has to focus on the specific choice of varieties with regard to maturity group, optimised timing of the blooming and fruiting period and drought tolerance (*Passioura* 2006). The increase of the transpiration efficiency of plants is also of great importance.

Timing in wheat farming is becoming more relevant, with varieties that ripen fast and are therefore not exposed to summer droughts and heat. In Brandenburg early-maturing wheat varieties are cultivated more frequently. This measure can raise the transpiration efficiency of plants as water is available when needed. Improvements of frost tolerance by genetic modifications is being investigated. Further research may be successful in the wake of the discovery of the core-binding factors (CBF) (*Thomashow* et al. 1999), which greatly improve frost tolerance of the plant *Arabidopsis*.

Drought tolerant varieties will be emphasised in genomic breeding. This includes the functional analysis of natural biodiversity, the genetic analysis of complex characteristics and the development and implementation of optimised breeding strategies. The cultivation of genetically engineered crops is under discussion (e.g. *Herve* and *Serraj* 2009). *Passioura* (2006) reports a large number of patents (> 100) on genetic modifications and sequences that enhance drought tolerance. With this measure the **transpiration efficiency** of plants may be raised, as less water is needed to obtain the same yield.

4.2.2 Seeding

High crop density, by means of fast and complete development of ground cover and deep root penetration, is a result of high-quality seed-bed preparation and seeding. Crustification of the soil surface, irregular sowing depth and low-quality seeds may lead to incomplete stands (*Passioura* 2006). Regular and dense sowing may raise water use efficiency, as the ratio of transpiration of the plants to evaporation from the soil is increased. Dense crop is able to use soil moisture resulting from rare, short-lasting and stronger rainfalls more easily (*van Duivenbooden* et al. 2000). A sparse plant cover with row crops, like sugar beet, leaves the soil uncovered for a relatively long period, thus leading to high, unproductive water losses via evaporation. Drying up of the soil between the plants at a later time produces palpable heat and a higher transpiration of the individual plant. On the other hand, a reduction of crop density will provide more water per plant. By contrast with row crops, lower sowing densities are recommended for grain crops (*Ehlers* 1996).

Direct drilling might be useful in improving water use efficiency as it is an extensive and humus-preserving method (*Passioura* 2006). A long-term study of direct drilling of maize on silty-sandy soils in Thyrow (Teltow-Fläming district, Brandenburg), however, was not successful (*Photo 1*).

Plants from ploughed-in seeds grew to be more lush and more vital than those from direct drilling. Comparisons between ploughed-in seeds and seeds from non-turning tillage, however, showed very little difference – a result which did not change over years – as high yields of the latter plants could be observed later. An increase in water use efficiency was not obtained with direct drilling. To achieve the same yield with direct drilling, higher amounts of fertilisers have to be applied. On fields under direct drilling the application of the Glyphosat herbicide is necessary, but as the continuous usage of Glyphosat leads to acquired resistances of the weeds, its application is not recommended.

Considering the current vegetative period could lead to increasing water use efficiency by means of prompt sowing, weed destruction before or during sowing and pre-germination of seeds.

Yield failures are higher when the stress factor occurs during sensitive growing periods such as leaf growth, blooming period or fruit formation. In this context, the negative impact of spring droughts, as in 2009, must be regarded as more critical than that of summer heat (*Gaul* 2009). The sufficient availability of water is the crucial condition for germination. After a drying period in summer, a relatively shallow wetting zone in the seed bed after summer rains may be sufficient for germination. If, however, the deeper soil horizons are not further replenished with water, the young crop grows sickly (*Ehlers* 1996). Summer annual varieties have to be sowed at the earliest time possible to match the juvenile development with the period of short-day conditions. The sowing of winter annual crops must allow for the completion of the autumnal development stages and winter hardiness, thus giving enough time for vegetative and generative spring growth (*Diepenbrock* et al. 2005).

4.2.3 Fertilisation

The nutrient supply of young plants promotes the fast development of ground cover, accompanied by a reduction of evaporation. The formation of a dense root mass, enabling the plants to use water and nutrients sufficiently in future, is improved by an optimal nutrient supply.

During recent years the application of fertilisers had to be increased due to climate change. Early droughts caused the degradation of crop growth and a non-optimal application of fertilisers (*ED-Report Düngemittel* 2007). Hence, the risk of a negative impact of fertilisation is enlarged.

Excessively high nitrate levels derived from fertilisation, or from mineralisation of organic matter in the soil, may lead to strong plant growth and excessively high water demand before the blooming period. The crop sets seed in large numbers but fails to produce and transfer sufficient carbohydrates for seed filling (*Angus* and *van Herwaarden* 2001).

Especially for water use under drought stress, the **potassium supply** has to be ensured. Field tests on the manuring effect of potassium in relation to soil concentration revealed that a medium concentration of potassium in the soil resulted in optimal yields and yield stability (*Kerschberger* and *Frey* 2009). The sandy soils in Brandenburg need special consideration, as they show high potassium leaching combined with low potassium replenishment. Potassium concentrations range from 0.2 to 3 %, which equals 8,000 to 120,000 kg/ha K_2O at a depth of 30 cm in the topsoil. Just a small part of the potassium is available for the plant roots (*Knittel* and *Albert* 2003). Sufficient potassium supply for the crop raises the transpiration efficiency.

To **support root formation** proper P and Mn supplies ought to be provided. Extensive root formation may raise the tolerance against drought stress, because plants with well-developed roots have access to a larger fraction of the soil moisture. This amounts to a spatial increase of the water reservoir. On the other hand, root density may be reduced in sandy soils due to water deficits (*Knittel* and *Albert* 2003). According to *Li* et al. (2009) plant roots in arid areas need to grow down to increasingly greater depths in order to find available nutrients in the soil moisture. The same authors report a linear relation between fruitage and root mass.

4.2.4 Optimising crop rotation and intermediate crops

Cultivated crops with a long vegetative period, e.g. lucerne, sugar beet and maize, can severely exhaust the soil water reservoir. Where stand formation of the follower crop is endangered by a large water deficit in autumn, flexibility must be shown and the summer crop sown first instead of the winter grain (*Ehlers* 1996). In areas with early droughts the cultivation of intermediate crops as undersowing is not recommended, because they may fail to become established due to aridity or because they may compete with the cover crop (*Ehlers* 1996).

Intermediate crops and full-season crops may contribute to an increase in water use efficiency if they taproot, like e.g. lucerne, which may pierce and exploit deeper soil horizons. This in turn leads to a spatial enlargement of the water reservoir. Thus, deep-root formation of the follower crop may be encouraged which contributes to improving water supply and dry-matter production by reducing infiltration and increasing transpiration (*Ehlers* 1996).

The general objective of plant protection is to defend against diseases, pests and weeds. With regard to water use efficiency, the main impacts of plant protection are improvement thanks to healthy plants and lower competition for soil water between cultivated crops and weeds. Non-productive transpiration is reduced and the transpiration efficiency is increased.

Plant protection may be indirect or direct. Indirect control measures include e.g. proper choice of cropping site, fertilising, preference of resistant varieties and adequate cultivating methods. Direct control measures are divided into biological, biotechnical and physical methods and chemical plant protection.

4.2.5 Irrigation

Different irrigation scheduling systems are listed here in the order of increasing precision: direct measurement of the soil moisture by sensors, calculation of the water balance (*Geisenheim* method) and application of multilayer soil moisture models and evapotranspiration models (e.g. the BEREST 90 model developed by *Wenkel* et al. 1980). Selecting efficient irrigation techniques may influence the amount of used water.

If stored precipitation water is available for irrigation, the green-water fraction of the water reservoir is enlarged. Sprinkling irrigation techniques cause major water losses due to wind drift and evaporation. Surface and subsurface micro-irrigation and surface irrigation are more efficient.

Drip irrigation uses a network of perforated piping installed at or just below the surface of the soil. Using this method, non-transpirative water losses are substantially reduced, as there are no losses due to wind drift, infiltration or surface water runoff. Automated drip-irrigation systems using computerised sensors to monitor the exact amount of moisture needed by the plant are especially economical. Withdrawal of ground water, surface water or bank filtrate reduces the proportion of green-water in the water reservoir.

Precision irrigation systems irrigate only specific parts of a field, thus adjusting the amount of irrigation water to the water demand of the plants. In the case of deficit irrigation, water administration is reduced during critical growth periods, so that only a part of the root-penetrated soil zone is supplied with water. This takes advantage of physiological stress responses of the plants and can thus improve the relative yield and water productivity. *Zhang* and *Oweis* (1999) reported a 50 % reduction in irrigation leading to a yield reduction of only 10 to 15 % for arid areas. To reduce irrigation the number of subsequent irrigation applications is cut and irrigation furrows are only filled half or built further away from each other.

4.2.6 Water-saving storage and processing of field crops

After the harvest various field crops are washed or cooled with water. The amount of water used for washing varies greatly, depending on washing method, recycling of sewage, availability of water and product. Fruits are generally not washed. Potatoes are washed (water use: 200 l/t), as are carrots (up to 300 l/t). Blanched asparagus for instance needs to be cooled after washing (average total water use: 500 l/t; pers. comm. *Geyer* 2009). In 2007 the amount of water used for washing and cooling 13,271 t asparagus harvested in Brandenburg totalled 6,600 m³. In the same year, 90,000 m³ water were needed to wash 361,000 t potatoes. In order to reduce the use of process water, on some farms washing water is sieved, caught in sedimentation tanks and recycled.

4.3 Livestock farming

In livestock farming our investigations focused on reducing drinking water demand and increasing

Tab. 6 Evaluation of the measures presented with regard to their impacts on the livestock farming system: + positive impact on the corresponding target parameter, – negative impact on the corresponding target parameter, o no effect / *Bewertung der vorgestellten Maßnahmen der Expertise nach ihren Wirkungsweisen im Bereich der Tierhaltung: + positiver Effekt auf die entsprechende Zielgröße, – negativer Effekt auf die entsprechende Zielgröße,* o *kein Effekt*

Livestock farming	**Increase of transpiration efficiency**	**Seasonal or spatial increase of the water reservoir**	**Increase of non-irrigative proportion of water reservoir**	**Decrease of non-transpirative water losses**	**Economising on process water and drinking water**
Maintenance at regular intervals	O	O	O	O	+ Reduction of drinking water demand
Dimensioning of drinking water installation	O	O	O	O	+ Reduction of drinking water demand
Soaking	O	O	– Withdrawal of groundwater, surface water or bank filtrate for cleaning	O	+ Increase of water use efficiency of cleaning
Use of broom for cleaning	O	O	O	O	+ Water-saving cleaning
Separate collecting, storing and applying of milk house and milking house waste water	O	O	+ Enlargement of water reservoir of ground water, surface water and bank filtrate	O	+ Saving of process water
Recycling of milk-tank cooling water	O	O	– Withdrawal of groundwater, surface water or bank filtrate for cooling of milk-tank	O	+ Saving of process water by recycling
Productive use of cooling water for roof cooling	O	O	– Withdrawal of groundwater, surface water or bank filtrate for cooling	– Unproductive evaporation from stable roofs, due to too large amounts of water used for sprinkling	+ Water-saving cooling
Cooling by spray humidification only up to a certain atmospheric humidity (< 60 %)	O	O	– Withdrawal of groundwater, surface water or bank filtrate for cooling	O	+ Water-saving cooling
Appropriate nozzles and valves	O	O	– Withdrawal of groundwater, surface water or bank filtrate for cooling	O	+ Avoiding large water drops and trickling of valves
Reduction of water-based cooling processes	O	O	O	O	+ Water-saving cooling

water use efficiency of cleaning processes and cooling processes (see *Tab. 6*). Mainly groundwater, surface water, and, in smaller amounts, bank filtrate are used in livestock farming in Brandenburg.

4.3.1 Reduction of drinking water demand

The water demand of farm animals should be interpreted separately from the real water demand. Loss of water due to cleaning of the drinking systems, leakage or animal activity increase water demand. To improve water efficiency of drinking water demand, these losses should be cut by **regular maintenance of the systems**. Process and drinking water can be saved in this way. The **dimensioning of the drinking systems** is important for optimised drinking water demand with resulting minimal water waste. Often problems arise concerning pipe dimensioning. This may lead to pressure at the drinking troughs being too high or too low, with associated water wastes.

4.3.2 Increase in water use efficiency of cleaning processes

The process water demand for cleaning of milking parlour and assembly yard is very important in dairy farming. Requirements depend on the kind of milking parlour (method of cleaning, number of milking clusters, length of milk lines; KTBL 2008). Automatic milking systems (AMS) use more water than conventional milking systems due to a large number of cleaning intervals. The daily water use lies between 0.5 and 0.8 litres per kg of milk. Cleaning the outside of the AMS and its tank takes 0.1 to 0.15 litres per kg of milk (KTBL 2008). The animal housing is cleaned using a high pressure cleaner. *Tab. 7* shows the process water demand for the cleaning of animal housing.

With **soaking,** the process water demand for the following cleaning of animal housing is reduced. A cooling sprinkler system can be used for this purpose. After soaking the animal housing, manual cleaning with a high pressure cleaner follows (KTBL 2009a). Even if cleaning and disinfection at regular intervals is recommended (KTBL 2008), daily **cleaning** can be performed **with a broom** to save water (*Hörnig* und *Scherping* 1993). Furthermore, **wastewater from the milking house can be collected, stored, and applied** to fields or grasslands where applicable (*Hörnig* und *Scherping* 1993).

Tab. 7 Daily water demand for various operations during cleaning and disinfection of animal housing on a dairy farm (KTBL 2008), in pig husbandry (KTBL 2009a), and on a poultry farm (KTBL 2009b) / *Täglicher Wasserbedarf verschiedener Arbeitsgänge während der Reinigung und Desinfektion der Stallgebäude in der Rinderhaltung (KTBL 2008), Schweinehaltung (KTBL 2009a) und Geflügelhaltung (KTBL 2009b)*

Operation	Water demand [l/m²]
Soaking	1.0 – 1.5
Cleaning	10.0 – 30.0
Disinfection	0.3 – 1.0

4.3.3 Increase in water use efficiency of cooling processes

The milk tank is often cooled by water. For the purpose of water saving, this water should not be disposed of, like rainwater or waste water. It should be reused for cleaning processes within the milking parlour or rearing compartment of the animal housing, as drinking water for the animals, or for heat recovery through **closed circuit** storage (*Hörnig* und *Scherping* 1993).

Various technical water-consuming solutions are employed for comfortable ambient temperatures for animals in housing structures.

- Sprinklers on the roof of the animal housing lower the temperature of the roof and minimise the heat input through this route.

- Cooling of the animal housing via spray humidification or sprinkling directly on the animals;

- Cooling through air moistening: cooling of the sucked-in air with spray-moisturising or moisturising of pad systems. The pad systems are made of cellulose, synthetic fibre or chequered bricks which are sprinkled from above with water.

For more **productive use** high water losses through the roof gutter during the cooling process should be avoided. Cooling by air dropping or sprinkling within the housing will raise the air humidity and reduce transpiration by the animals. **Cooling by spray humidification should only be applied up to atmospheric humidity levels of < 60 %.**

Appropriate nozzles and valves may prevent excessively large water drop and dripping.

It is generally recommended that **water-based cooling processes be reduced** in the planning of newly constructed animal housing, using simple measures like

- Orientation of the animal housing and location of fresh air intake;.

- Reduction of the window areas of walls;

- Using the day and night temperature fluctuation in the regulation of the ventilating system during times of high temperatures.

5. Outlook

Germany is the largest agricultural producer of milk, pig meat and canola in the 27-strong European Union and the second largest producer of cereals, potatoes, sugar beet and beef. In general, the perspectives for agriculture in Brandenburg, Germany, and the EU are favourable.

With worldwide climate change, population growth, changes in livestock and crop farming, and the increasingly strained regional water balance, enormous challenges have to be faced in the agricultural sector in Brandenburg.

As water will be more valuable in a longer time frame compared with today, research into the optimum use of the resource will be key to ensuring global food security in the future. Given the low precipitation compared to the rest of Germany and the frequently sandy soils with a low storage capacity, in Brandenburgg the use of water can be considered a limiting factor in many farming systems, even without climate change effects.

This study asked whether regional water resources can be used more efficiently by Brandenburg's farming systems. In view of the complexity of the agricultural systems in Brandenburg, general measures to raise water use efficiency could not be derived. Site-specific tillage practices and crop patterns adjusted to recent weather conditions may reflect the specific diversity of Brandenburg more efficiently.

We recommend the following strategy:

- The long-term field experiments in Brandenburg must be continued to gain reliable results of site-specific measures.

- The assessment and adoption of site-specific adaptation strategies and measures from different countries (Germany, South Africa, Australia and Nebraska/USA) could allow the development of alternative strategies for Brandenburg. One example is the agri-benchmark network jointly managed by the Johann Heinrich von Thünen Institute, Germany (vTI) and the German Agricultural Society (DLG).

- On the one hand, higher flexibility on the part of the farmers must be achieved; on the other hand, a certain degree of planning reliability for the farmers is needed. To support such planning reliability an all-risk insurance (*Gaul* 2009) and the already existing governmental drought relief programme (German: *Dürrehilfsprogramm)* could be helpful.

- Analysing the risk for drought-related yield losses of arable crops and grasslands based on a threshold for water stress, together with the trend in the occurrence of periods with insufficient soil water availability according to *Fuhrer* and *Jasper* (2009). The development of functioning farming units with site-specific measures similar to hydrological response units could be interesting. One important aspect would be to incorporate water efficiencies in such a spatial analysis.

- The important and missing quantification of the improved water management by using the presented measures is a great challenge and will be investigated within the Gottfried Wilhelm Leibniz Scientific Community (WGL) young investigators group "World Food Supply and Water Resources: An Agricultural-Hydrological Perspective, AgroHyd" established 2011 at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB). The quantification of the measures will be pursued towards a further practical and applicable approach.

Applied agricultural research must contribute to maintaining and developing the competitiveness and sustainability of agriculture in Brandenburg. Innovative measures should be translated into practice with the help from the farmers in determining appropriate action. Innovations will become increasingly relevant for the optimum use of global and regional water resources. It should be kept in mind that environmental impacts of agricultural production should be assessed considering not only one resource but as many as feasible. The overall goal should be to produce sufficient high-quality food, feed and raw materials from our finite supplies of water, soil, energy and carbon.

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Summary: Agricultural Water Management in Brandenburg

The present study explores whether regional water resources can be used more efficiently by Brandenburg's agricultural systems. A systematic analysis of measures to raise the water efficiency follows the description of agriculture in Brandenburg today. Brandenburg's agricultural systems are separated into three sections: soils, plant production and livestock farming. Within these sections measures to increase water efficiency are listed and analysed with reference to five objective criteria for raising water use efficiency. In the soil section the measures soil tillage and humus conservation management are assigned to the criteria. The following fields in the plant production section are similarly investigated: breeding, seeding, fertilisation, tactically chosen crops, avoidance of competition by herbicide use and efficient irrigation practices as well as water-saving storage and cleaning of field crops. In livestock farming the supply of drinking water and cleaning and cooling processes are analysed. In view of the complexity of the agricultural farming systems in Brandenburg, general measures to raise water use efficiency could not be derived. Site-specific tillage practices and crop patterns adjusted to the recent weather conditions may reflect the specific diversity of Brandenburg more efficiently.

Zusammenfassung: Wassermanagement in der Landwirtschaft in Brandenburg

Boden und Wasser sind weltweit die wichtigsten Produktionsfaktoren in der Landwirtschaft. Die bedarfsgerechte Wasserversorgung der Kulturpflanzen und Tiere stellt im Zuge des Klimawandels eine große Herausforderung für die Landwirte im Raum Brandenburg dar. Eine systematische Analyse von Maßnahmen, die die Wassereffizienz steigern könnten, folgt in der vorgestellten Studie einer Beschreibung der Landwirtschaft Brandenburgs. Die drei analysierten Teilbereiche Boden, Pflanzenproduktion und Tierhaltung wurden analysiert und nach ihrer Wirkungsweise in fünf prinzipielle Zielgrößen eingeordnet, die der Erhöhung der Wassereffizienz dienen. Im Bereich Boden wurden die Bodenbearbeitung und die Humuswirtschaft untersucht. Auf dem Gebiet der Pflanzenproduktion erfolgte die Analyse der Maßnahmen Züchtung, Säen, Düngen, Optimierung der Fruchtfolgen und Zwischenfrüchte, Vermeidung von Konkurrenzen durch Pflanzenschutz und die effiziente Bewässerung, Lagerung und Verarbeitung von Feldfrüchten. In der Tierhaltung wurde das Einsparen von Prozesswasser durch die Reduzierung des Tränkwasserbedarfs, durch die Steigerung der Wassereffizienz der Reinigungsprozesse und der Kühlung untersucht. Da das Brandenburger System „landwirtschaftlicher Betrieb" zu komplex ist, war es nicht möglich, pauschale Aussagen zu einem „Besser" oder „Schlechter" der verschiedenen Maßnahmen, die die Wassereffizienz steigern könnten, zu treffen. Eine standortspezifische Bodenbearbeitung und standortspezifische Bodenbearbeitungsfolgen, die auch an die aktuelle Witterung angepasst werden, können die Vielfalt der Brandenburger Ackerbausysteme effektiver berücksichtigen.

Résumé: Gestion de l'eau dans l'agriculture en Brandebourg

Cette étude se consacre à la question suivante: L'efficacité de l'utilisation des ressources en eau régionales par l'agriculture en Brandebourg peut-elle être améliorée ? Après avoir présenté les caractéristiques de l'agriculture brandebourgeoise actuelle, l'étude procède à une analyse systématique de mesures pouvant accroître l'efficacité de l'utilisation de l'eau. L'étude considère trois composantes des systèmes agricoles brandebourgeois: le sol, la production végétale et l'élevage. Pour chacune, les mesures permettant d'accroître l'efficacité de l'utilisation de l'eau ont été répertoriées et analysées à travers cinq grandeurs agissant sur l'efficacité de l'utilisation de l'eau. Pour le sol ont été analysés à la lumière de ces grandeurs: le travail du sol et la conservation de l'humus. De même, pour la production végétale, les mesures suivantes ont été considérées: sélection, semis, fertilisation, choix tactique des cultures, protection des plantes contre la concurrence, de même que les pratiques d'irrigation et les techniques de stockage et de nettoyage des récoltes économes en eau. Dans la section élevage, l'abreuvement du bétail ainsi que les procédés de nettoyage et de refroidissement ont été analysés. En raison de la complexité des systèmes agricoles en Brandebourg, il n'est pas possible de déduire de ces analyses des mesures de portée générale pour accroître l'efficacité de l'utilisation de l'eau. L'adaptation des pratiques de travail du sol et des rotations aux caractéristiques locales et aux conditions climatiques actuelles pourraient permettre de refléter plus efficacement les spécificités régionales.

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