R-2166
[1-9]

REVIEW ARTICLE

Agricultural Reviews, Volume Issue : ()

Principles, Positives and Limitations of Conservation Agriculture: A Review

C. Swaminathan, E. Sobhana, P. Kannan, M. Mohammed Yassin

10.18805/ag.R-2166

ABSTRACT

Lessons learnt from past experiences push for an alternate way of crop production. One such is Conservation agriculture (CA), which can be seen as a new way forward for conserving resources and enhancing productivity to achieve goals of sustainable agriculture. In recent past, progressive and significant efforts are made to develop, refine and disseminate conservation-based agricultural technologies across globe. Tremendous efforts on zero-till practices and surface management with crop residues for crop production were reviewed. This work was done at Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai -625 104, Tamil Nadu, India. A systematic cum integrative review of research work done in different parts of World, particularly in India was comprehended. Literature search was done during 2020. About 200 review and research papers were screened from various databases like TNAU e-library, ARCC journals, Google Scholar, Research gate and Scopus and 84 papers were used. This review article comprehensively documents major principles of CA along with extent and spread of CA across the globe. It also highlights CA in Indian perspective. Various merits and demerits were also discussed with literature support. This review paper discusses rising concerns of conventional agriculture systems with regard to its adoption, positives and negatives of conservation agriculture in promoting conservation agriculture in tropics.

Key words: Conservation agriculture, Cover crops, Crop rotation, Field traffic, Minimum tillage, Soil cover, Sustainability.

World has faced many challenges and one such is to feed growing and ever increasing population under a changing climate with reduced external inputs (Pittelkow *et al.,* 2015) on a sustainable intensification mode (Tilman *et al*., 2011; Vanlauwe *et al*., 2014; Giller *et al.,* 2015) with minimal negative effect on environment (Foley *et al*., 2011). In recent times, Conservation agriculture (CA) has been highlighted as an alternative and viable option for Sustainable Intensification (Hobbs *et al*., 2008; Pretty and Bharucha, 2014) of food production. Under conventional agricultural systems, principle indicator of non-sustainability is soil erosion and declining of soil organic matter as mainly caused by: (1) heavy field traffic induced degradation of soil structure, water and wind erosion leading to poor infiltration rate, crusting of soil surface, soil compaction, (2) poor recycling of organic materials and also (3) monocropping (Kavita Bhadu *et al*., 2018).

Methodology

Review work was carried out at Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India. Almost 10 months during 2020 had been spent in collecting literature which includes 3 months for manuscript writing. About 200 scientific papers were screened, shortlisted and 84 papers used to prepare this manuscript. For searching of research papers, various data bases such as TNAU e library, ARCC journals, Google scholar, Research gate and Scopus were used.

History, development and importance of CA

Repetitive tillage operations in conventional method of field preparation lead to decline in soil organic matter through accelerated oxidation and declining of soil biodiversity and fertility. Further, burning of crop residues causes pollution and loss of valuable plant nutrients. Retention of crop residues on soil surface along with zero-tillage kicks off processes that lead to enhanced soil quality and overall resource augmentation (Das *et al.,* 2013).

The term conservation agriculture (CA) represents a package of agronomic technologies that permit for minimum disturbance of soil, maintenance of soil cover with crop residues and a system approach with crop diversification and rotation both at spatially and temporally (FAO, 2008). Current global estimates indicates that CA has been adopted in 124 m. hectares (Friedrich *et al*., 2011), 87% of which is concentrated in five countries *viz*., United States, Brazil, Argentina, Australia and Canada (26.5, 25.5, 25.5, 17.0 and 13.5 m. ha, respectively). Further, a host of supplementary environmental benefits have been theorized and are now

Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India.

Corresponding Author: C. Swaminathan, Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India.
Email: brownrevolution@yahoo.com

How to cite this article: C. Swaminathan, E. Sobhana, P. Kannan and M. Mohammed Yassin (2021). Principles, Positives and Limitations of Conservation Agriculture: A Review. Agricultural Reviews. DOI: 10.18805/ag.R-2166.

Submitted: 22-01-2021 **Accepted:** 16-04-2021 **Online:** 11-05-2021

documented (Hobbs *et al*., 2008) and also in smallholder farming systems in sub-Saharan Africa and South Asia (Pittelkow *et al.,* 2015).

For first time during 1930s, tillage operations in fragile ecosystems were questioned, as dustbowls devastated wide areas of mid-west United States, which led to farm scientists to consider about reducing tillage and keeping 'soil covered'. This paved way for introduction of conservation tillage aiming at soil protection. Later in 1940s, seeding machinery developments was allowed to seed directly without any soil tillage. Parallely, Faulkner (1945) in his book "Ploughman's Folly" and Fukuoka (1975) with "One Straw Revolution" explained principles and concepts similar to today's CA principles. However, it was only in 1960s, no-tillage entered into farming practices in USA (Kassam *et al*., 2010, 2014). However a Tamil Laureate from India had written ten couplets about farming and plough in his collection on '*Thirukkural*' and he suggested following measures as early in 50 BCE. English translation of Couplet 1037: (Thiruvalluvar 50 BCE, Tamil Laureate from India).

Reduce your soil to that dry state, when ounce is quarter-ounce's weight;

Without one handful of manure, Abundant crops you thus secure.

English translation of Couplet 1038: (Thiruvalluvar 50 BCE).

To cast manure is better than to plough; Weed well; To guard is more than watering.

In early 1970s no-tillage reached Brazil, as farmers along-with scientists transformed these technologies in to a system, presently known as CA, however it took another 20 years before CA principles reached a significant adoption levels. Simultaneously, impetus on improvements in designing of farm equipment especially seeding implements and zero/minimum tillage focussed agronomic practices was developed to ensure crop production. It still continuing as there is no end for creativity of farm scientists and farmers. From early 1990s CA started growing exponentially, leading to a revolution in agriculture of southern Brazil, Argentina and Paraguay (Kassam *et al*., 2015).,

Derpsch and Friedrich, (2009) listed many practices adopted under rain-dependent marginal soils in different countries, like mulch cover for avoiding soil crusts and surface sealing; adopted (*e.g*., Australia, Argentina); small land holders (< 0.5 acre) practice No-tillage CA in China, Zambia and Paraguay; and larger holdings in Argentina, Brazil and Kazakhstan.

Lack of technical knowhow, mind rejections due to traditions and prejudice, poor policies and direct farm payments (EU), non-availability of suitable equipment and machineries (many countries of world) and lastly absence of strategies for weed and vegetation management, barred CA from acceptance among farmers (Friedrich and Kassam, 2009; Jat *et al*, 2014; Farooq and Siddique, 2014).

Many bilateral and multi-lateral donors to come forward to support and spread CA as it is sustainable, but intensive production system through awareness creations that led to growth of zero or No-till/CA organizations worldwide and also framing of national and regional policy and institutional support across world (Kassam *et al*., 2015).

Definition and description of conservation agriculture

According to (Hubbard *et al*., 1994; Karlen *et al*., 1994) CA is a common title for a set of agricultural practices intended to enhance sustainable food production by conserving and protecting existing and available soil, water and biological resources thereby keeping external inputs at minimum (Garcia-Torres *et al*., 2003). This term is usually applied to no-tillage, direct drilling, or minimum tillage practice when it is coupled with crop residue cover of 30% of soil surface and associated with conservation of time, fuel, earthworms, soil water and nutrients (Baker *et al*., 2002). Stagnari *et al*. (2009) observed that, conservation tillage can be a transition step towards CA agriculture which still depends on tillage as structure-forming element in soil.

CA is not a routine and usual business as observed by Dumanski *et al*. (2006). FAO (2014a) describes it as a resource saving crop production concept, which is based on enhancing above and below ground natural and biological processes. CA is to 1) achieve adequate profits 2) sustained production levels and 3) conserve environment. It aims at reversing degradation process which is inherent to conventional agricultural practices besides ensuring efficient utilisation of natural resources in an integrated way, combined with external inputs. Hence, CA is a resource efficient/ effective agriculture Suraj Bhan and Behera (2014).

Carbon sequestration at about 0.2 to 1.0 t/ha/year or more depending on location and management practices (Gonzalez-Sanchez *et al*., 2012; Sa *et al*., 2013 and Corsi *et al.,* 2014) is added benefit of CA. Reduction in labour requirements by 50% helps farmers to save on time, energy and machinery costs (Saturnino and Landers, 2002; Baker *et al*., 2007; Lindwall and Sonntag, 2010; Baig and Gamache, 2009; Crabtree, 2010). More than 60 percent energy savings was reported by Sorrenson and Montoya (1991).

Need for conservation agriculture

As conventional intensive tillage-based production systems has many deleterious effects on natural resources such as soil, water, terrain, biodiversity and associated ecosystem services providers (Montgomery, 2007; Kassam *et al*., 2013 and Dumansky *et al*., 2014) which leads to degradation of land resources and declining of factor productivities thereby affecting crop yields (Goddard *et al*., 2006; Jat *et al*., 2014 and Farooq and Siddique, 2014) and 30 percent of greenhouse gas emissions (IPCC, 2014), there is a need for sustainable yet intensified production system that ensures remunerative agriculture and natural resource conservation and harnessing environmental services (FAO, 2011a). Further, it should mitigate factors that cause climate change and also enhance soil biodiversity to improve ecosystem services for better productivity and environment. (Kassam *et al.,* 2015).

Another set of scientists (Kassam *et al*., 2013; Jat *et al*., 2014; and Siddique and Farooq, 2014) said CA is a combination of soil-crop-nutrient-water-landscape system management practices which saves on energy and mineral nitrogen use; enhances soil biological activity. However, CA should to be incorporated with integrated pest management, plant nutrient management, weed and water management (FAO, 2011).

Accusation of conventional agriculture for soil erosion problems, surface and underground water pollution, water consumption (Wolff and Stein, 1998) and also for land resource degradation, wildlife and biodiversity reduction, low energy efficiency and contribution to global warming problems (Boatmann *et al*., 1999), pushed farming community to seek alternative in form of CA, which offers a permanent soil cover, natural increase of organic matter content and also stresses conservative way of cultivation soil, air, water and biodiversity (Derpsch *et al.,* 2010; Derpsch *et al*., 2011).

Extent and adoption of CA in World and India

At World level

A steady increase in adoption and spread of Conservation agriculture practices worldwide has been evident as about ~8% of world arable land (124.8 m ha) is now under CA (FAO, 2012; FAO, 2014b) as it is a resource-saving but intensified agricultural production system that aims to achieve good plant nutrition and pest management practices besides, high yields while enhancing natural resource base Abrol and Sangar (2006) were.

CA has now emerged as an effective alternative agricultural strategy to achieve sustainable agriculture goals as it is able to address increasing concerns of grave and extensive problems of natural resource degradation and environmental pollution. According to latest estimates, CA has been followed in 80 m. ha, largely under rainfed conditions and area is expanding rapidly (Harrington and Olaf, 2005). USA took a lead in adopting CA with 18 m. ha and other leading countries following CA include Australia, Argentina, Brazil and Canada. In Latin America, it is rapidly accepted by farmers with policy decision to promote it. In Europe, France and Spain, CA has been adopted in about 1.0 m. ha area under annual crops. Further, a regional group uniting associations in UK, France, Germany, Italy, Portugal and Spain has been formed under banner of European Conservation Agriculture Federation. In Southeast Asia (Japan, Malaysia, Indonesia, Philippines and Thailand) CA is becoming popular under Community-led initiative strongly supported by Research and development organizations (Sangar *et al.,* 2005).

India

In India, though efforts were made to spread resource conservation technologies for years (Negi and Rana, 2016) but it is recently only technologies are accepted and adopted by farmers. This effort has been spearheaded by Rice–Wheat Consortium for Indo-Gangetic Plains, a CGIAR eco regional initiative involving several CG centres and National Agricultural Research System of India, Pakistan, Bangladesh and Nepal. In northwest regions of India, concerns about stagnating productivity, high production costs, deteriorating resource quality, decreasing water tables and escalating environmental problems push farm scientists to look for alternative technologies, particularly, in states of Punjab, Haryana and western Uttar Pradesh (UP) (Akhter *et al.*, 2004). But in eastern regions, low cropping system productivity is chief concern to seek alternatives, particularly in states of UP, Bihar and West Bengal. In these regions, primary focus was on development and adoption of zero-till cum fertilizer drill for sowing, raised-bed planting system, alternatives for residue management and to rice–wheat cropping system in relation to CA technologies, *etc* and it resulted in rapid adoption of zero-till drill sowing (Hobbs and Gupta, 2003) in an area of 1.0 m ha. plausible reasons for rapid adoption are less cost production, lowering incidence of weeds and minimised weedicide costs and, savings in water and nutrients management. Abrol and Sangar, (2006) were of opinion that zero-tillage combined with residue management favoured improvements in of availability of soil nutrients and moisture, recycling and soil biological activity and thus provided a more favourable environment for crop growth. Though, CA is being well thought-out as a road to sustainable agriculture, yet, in India, CA is a new concept and its roots are only now beginning to find grounds.

In India, Erenstein and Pandey (2006) and Piyush *et al.* (2018) conducted experiments to measure benefits of CA in Indo-Gangetic plains and found a few ground reality benefits harvested by farmers under CA was illustrated in Fig 3. Crops grown by adopting CA is climate resilient, ensures food security and soil nutrition besides reducing energy consumption as presently farmers are facing problem of labour shortage and drudgery of farming these are all can be reduced by conservation tillage practice.

Principles of conservation agriculture

CA practices followed in many parts of world are built on sustainable ecological principles (Wassmann *et al*., 2009; Behera *et al.,* 2010 and Lal, 2013). Balancing Resource use efficiency (RUE) and crop productivity is utmost essential for managing natural resources and to accomplish agriculture sustainability. Conservation agriculture fundamentally relies on following principles:

Minimal mechanical soil disturbance

Concept of 'biological tillage' is a natural phenomenon promoted by soil microorganisms through biological activity that produces stable soil aggregates and a range of sizes of pores thus allowing air and water entry and infiltration in soil. This process is comparable to mechanical tillage but mechanical tillage spoils soil biological structuring processes.

This facilitates gaseous exchange in root-zone, moderate oxidation of organic matter, soil pores assisted water movement, retention and release and restricts re-exposure of weed seeds and their germination (Kassam and Friedrich, 2009).

Permanent soil organic cover

Maintenance of permanent soil organic cover (at least 30 percent) with crop residues or cover crops ensures formation of a protective layer on soil surface which suppresses weeds; protects soil from impact of extreme weather patterns; helps to preserve soil moisture and avoids compaction of soil.

Besides, it protects soil from exposure to rain and sun, ensures continuous supply of food to soil organisms and alters soil microclimate for growth and development of soil organisms. In turn it improves biological activity in soil aggregation of soil particles and carbon sequestration (Ghosh *et al*., 2010).

Rotation of crops

Rotation of crops ensures a diverse "diet" to soil microorganisms and favours recycling of nutrients from deeper soil layers to surface through diverse rooting pattern of crops grown in rotation Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna.

Inclusion of legumes in cropping sequence and rotations negatively influences pest species through life cycle disruption and builds up biological nitrogen fixation (Kassam and Friedrich, 2009; Dumanski *et al.*, 2006). CA components and their positive interaction in soil and crop yield influencing factor are illustrated in Fig 1.

Controlling field traffic

Controlled traffic that lessens soil compaction could be another principle being pondered upon in recent years. In a long-run, CA practices are promising in terms of efficient rational use of resources and sustained productivity (Das *et al.,* 2014, Nath *et al*., 2017; and Oyeogbe *et al.,* 2018).

Advantages of Conservation Agriculture

Multifaceted benefits of CA are depicted in Fig 2. CA ensures (i) physical protection against weather (raindrops, wind, dry or wet periods), (ii) better soil structure and cohesion, (iii) helps in erosion control and nutrient transport and (iv) saves money, time and energy. CA promise great potential for different soils and agro-ecological systems. It is a farm-holding size neutral but CA adoption is most urgently required by smallholder farmers to reduce their cost of production, increase profit and save resources (Derpsch, 2008). Often conservation agriculture is misunderstood as organic farming. There are little differences between these two concepts. Though both have common ideology of improving soil health through natural resources; organic farming prohibits application of chemical inputs while CA permits.

CA is being promoted as a solution to increase crop productivity and food security (Hobbs, 2007) and has potential to reduce labour needs for land preparation and improve soil fertility while also reducing water stress in crops (IIRR, 2005). The Main objectives of conservation agriculture is reducing tillage, year round cropping, crop rotation, mulching may be live or residue. Due to reduced mechanical tillage, activity of micro flora and macro flora get increases that improves biological tillage of soil, that in turn improves soil structure and enhances the plant growth (Selvakumar and Sivakumar, 2021).

Constraints for adoption of conservation agriculture

Kavita Bhadu and her team in 2018 identified problems associated with conservation agriculture while adopting it and found that mind set of farmers is the major deterrent as they were educated extensively on conventional intensive

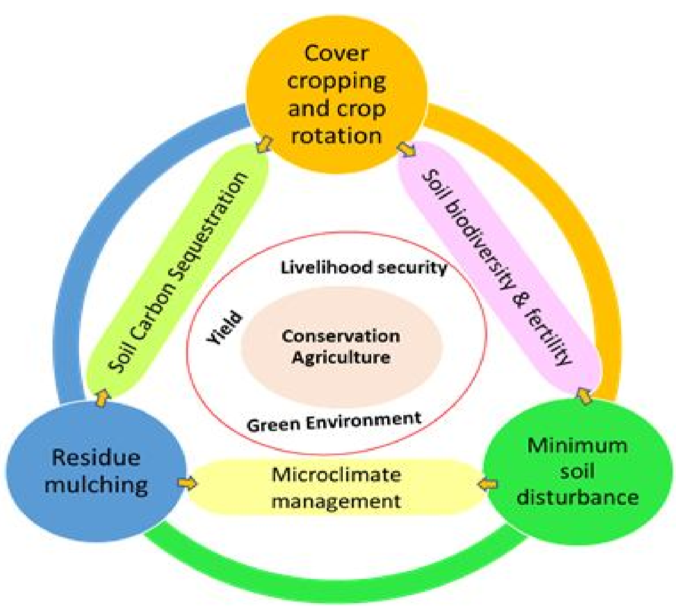

Fig 1: Components of conservation agriculture and their positive interaction with environment

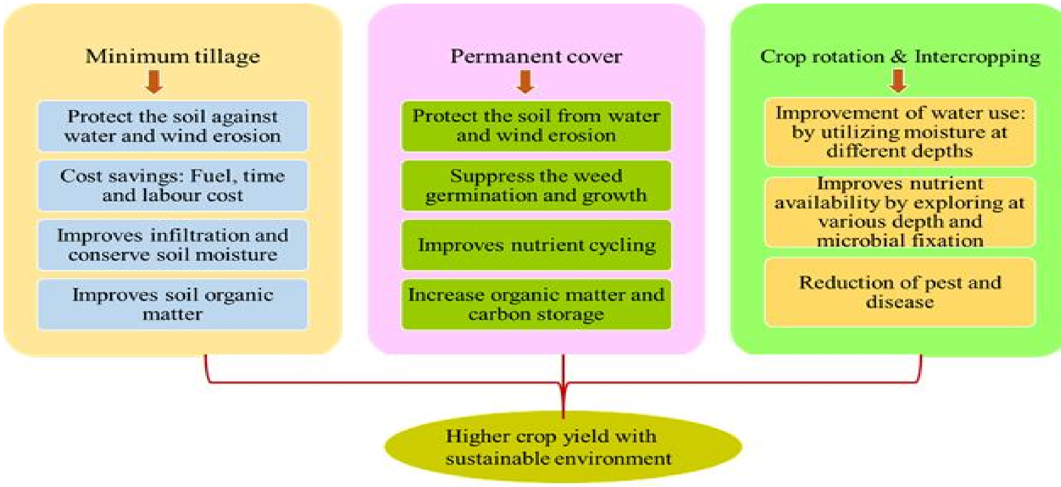

Fig 2: Conservation agriculture component wise soil, environment and yield benefits.

agriculture and use of external inputs. A few other constraints are:

In adoption of reduced tillage

- ✓ In absence of fertilizer minimum tillage may lead to nutrient immobility causing farmers to experience reduced yields (Giller *et al.*, 2009).
- ✓ Decomposition of crop residues can lead to short term nitrogen immobilization because of increased activity of soil organisms that lock up nitrogen in their bodies (Verhulst *et al.*, 2010).
- ✓ Even though tilling allows incorporation of residues and thereby, hastening decomposition process, it allows nutrients to be available for next season only.
- ✓ Weed control is primary motivations for tillage (Wall, 2007) as reduced tillage greatly increases weed pressure and it push for use of more labourers for weed control, but in CA, this constraint can be overcome with herbicides (Baudron *et al.,* 2007).
- ✓ Minimum tillage without herbicides faces challenge of controlling perennial weeds (Vogel, 1995).

In mulching

- ✓ Limited reliable markets and shortage of improved legume seeds is a peril for inclusion of legumes in crop rotation (Baudron *et al.,* 2007; Haggblade and Tembo, 2003).
- ✓ Greatest profits were earned from growing maize only when compared to cotton and sunnhemp in rotation despite yield increases from rotation.
- ✓ Inclusion of livestock challenges maintenance of mulch (Baudron *et al.,* 2007; Nyathi *et al*., 2011) and mulch sometimes favours crop pests infestation, especially termites (Nyathi *et al*., 2011). Furthermore, maintaining mulch may lock up nitrogen, requiring increased fertilization in short term (IIRR, 2005).

In crop rotation

- ✓ Crop geometry pushes farmers not to choose plant legumes in permanent planting basins (Baudron *et al.,* 2007).
- ✓ Key challenges for crop rotation are dearth of reliable markets for many leguminous crops and shortage of improved legume seeds (Baudron *et al*., 2007; Haggblade and Tembo, 2003).

Difference between conventional and conservation agriculture.

Practices	Conventional agriculture	Conservation agriculture
Land cultivation	Dominate nature	Least interference with natural processes.
Tillage	Excessive mechanical tillage and soil erosion	No-till or drastically reduced tillage (biological tillage).
Soil conservation	Low wind and soil erosion	High.
Residue management	Burning or removal (barren surface)	Retention (permanently covered).
Infiltration of water	Low	High.
Weed management	Killing weeds simultaneously stimulating more weeds to germinate	Problem of early stages but decrease with course of time.
Field traffic and soil compaction	Free-wheeling and high soil compaction	Controlled traffic and no compaction in crop area.
Cropping system	Mono cropping or monoculture	Diversified and crops rotated often.
Labour and time	Heavy reliance on manual labour and delayed often	Minimum mechanized operations and timely operations.
Adaptations	Poor adaptation to stresses	More resilience to stresses.

Source: (Sharma *et al*., 2012; Kavita Bhadu *et al*., 2018)

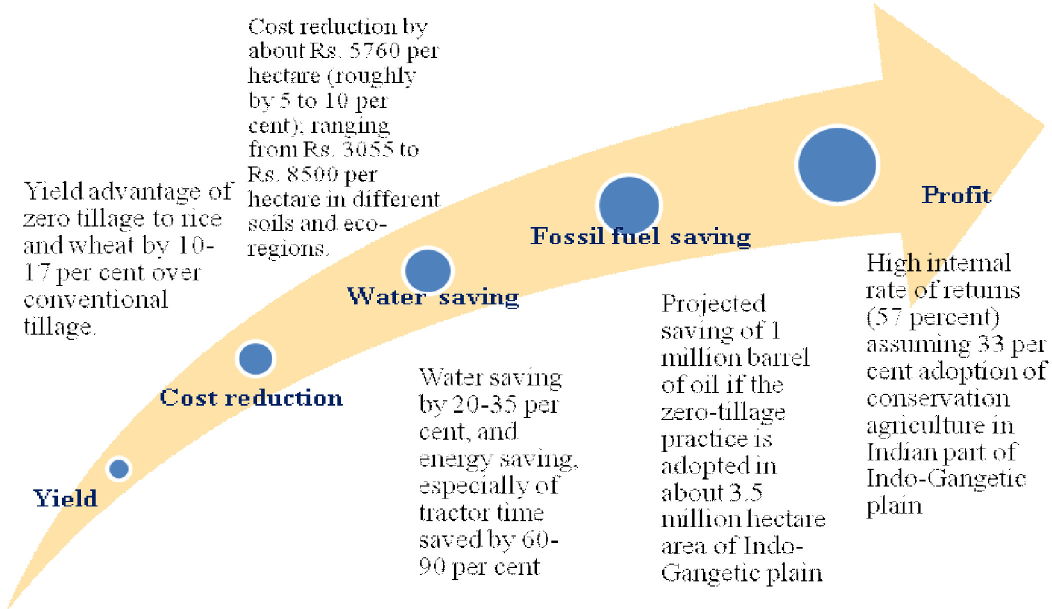

Fig 3: Benefits of Conservation Agriculture harvested by farmers on ground reality in tropics of India.

✓ Prospects of conservation agriculture in tropical regions

Indian farmers (70-75 percent) have only small and holdings and pay little attention to long term management of natural resources and can rarely afford input such as quality of seeds, fertilizer, heavy machines and herbicides for chemical weed management **(**Piyush *et al.,* 2018).

✓ Minimising cost of production

Zero-till technology for wheat saved $ 33 to 50/ha (Malik *et al*., 2005; RWC-CIMMYT, 2005; Poddar *et al.,* 2017) due to savings in energy, labour and inputs.

✓ Minimal weed infestation

A low incidence of invasive weed species *Phalaris minor* in wheat field was observed due to zero-till.

✓ Water saving

Water saving (20-30 percent) and also nutrients savings were achieved with zero-till planting under laser levelled and bed planted crops (De Vita *et al.,* 2007) stated that no-till planting had higher (>20%) soil water content under than under conventional tillage.

✓ Yield enhancement

About 200 – 500 kg ha^{-1} increased yield was found with no-till wheat compared to conventional wheat in Indo-Gangetic plains, it is due to avoidance of soil degradation, improved soil fertility, moisture and crop rotational benefits. (Hobbs and Gupta, 2004). A few studies claimed that CA results in higher and more stable crop yields (African Conservation Tillage Network, 2011), on contrary, there are also numerous examples of no yield benefits, yield reductions during initial years.

✓ Environmental benefits

Insisting on a permanent soil cover under CA eliminated *in situ* burning of residue, which avoids loss of plant nutrients.

✓ Crop diversification opportunities

Ample scope for crop diversification and cropping sequences/ rotations.

✓ Resource improvement

Zero-till coupled with crop residues management helps in soil structural improvement and efficient recycling and mulching moderates soil temperatures, reduces evaporation and improves biological activity (Suraj Bhan and Behera, 2014)

CONCLUSION

A paradigm shift from conventional system to Conservation agriculture is a necessity across tropical regions of world as it has wider scope for reversing downward gradient of resource degradation. Further, CA policies for regional/ country wise basis has to formulated first and networking all these has to done so as to have a global platform for CA. Adequate funding support has to be provided worldwide to intensify research as well as create awareness in tropical regions among small holding farmers to make CA, a mass movement.

REFERENCES

Abrol, I.P. and Sangar, S. (2006). Sustaining Indian agriculture-conservation agriculture -way forward. Current Science. 91(8): 1020-2015.

African Conservation Tillage Network. (2011) Soil changes resulting from long-term management practices in western Nigeria: Soil Science Society of America Journal. 43: 173-177. (www.act-africa.org)

Akhter, H.K. *et al*. (2004). Resource conserving technologies for rice production. Rice-Wheat Consortium Travelling Seminar Report Series 5, New Delhi: Rice-Wheat Consortium for Indo-Gangetic Plains, p. 36.

Baig, M.N. and Gamache P.M. (2009). Economic, Agronomic and Environmental Impact of No-Till on Canadian Prairies. Alberta Reduced Tillage Linkages. Canada. 135p.

Baker C.J., Saxton K.E. and Ritchie, W.R. (2002). No-tillage seeding: science and practice. 2nd Edition. CAB International. Oxford, UK. 341p.

Baker, C.J., Saxton, K.E., Ritchie, W.R., Chamen, W.C.T., Reicosky, D.C., Ribeiro, M.F. S., Justice, S.E. and Hobbs, P.R. (2007). No- Tillage Seeding in Conservation Agriculture - 2nd (Edn.). CABI and FAO, Rome. 326p.

Baudron, F., Mwanza, H.M., Triomphe, B. and Bwalya, M. (2007). Conservation agriculture in Zambia: A case study of Southern Province. Nairobi: African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Dévelopment, Food and Agricultural Organization of United Nations. https://www.researchgate.net/publication/238789786.

Behera, U.K., Amgain, L.P. and Sharma, A.R. (2010). Conservation agriculture: principles, practices and environmental benefits. In: [U.K. Behera, T.K. Das and A.R. Sharma, (Eds.)], Conservation Agriculture (pp. 28-41). Division of Agronomy, Indian Agricultural Research Institute, New Delhi. 110012, 216 pp.

Boatman, N., Stoate, C., Gooch, R., Carvalho, C.R., Borralho, R. and De Snoo, G. *et al*. (1999). Environmental impacts of arable crop production in European Union: practical options for improvement. A report prepared for Directorate-General XI of European Commission. Allerton Research and Educational Trust, U.K. 179p.

Corsi, S., Friedrich, T., Kassam, A., Pisante, M., (2014). A Review of Carbon Sequestration through Conservation Agriculture. In: [L.K. Heng, K. Sakadevan, G. Dercon, M.L. Nguyen, (Eds.)], Proceedings of International Symposium on Managing Soils for Food Security and Climate Change Adaptation and Mitigation. Food and Agriculture Organization of United Nations, Rome. 205-207.

Crabtree, B., (2010). In Search for Sustainability in Dryland Agriculture. Crabtree Agricultural Consulting. Western Australia. 204 pp. Available at: www.no-till.com.au.

Das, T.K., Bhattacharyya, R., Sharma, A.R., Das, S., Saad, A.A. and Pathak, H. (2013). Impacts of conservation agriculture on total soil organic carbon retention potential under an irrigated agro ecosystem of western Indo-Gangetic Plains. European Journal of Agronomy. 51: 34-42.

Das, T.K., Bhattacharyya, R., Sudhishri, S., Sharma, A.R., Saharawat, Y.S., Bandyopadhyay, K.K., Sepat, S., Bana, R.S., Aggarwal, P., Sharma, R.K., Bhatia, A., Singh, G., Datta, S.P., *et al.* (2014). Conservation agriculture in an irrigated cotton-wheat system of western Indo-Gangetic Plains: Crop and water productivity and economic profitability. Field Crops Res. 158*:* 24-33.

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N. and Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in Southern Italy. Soil and Tillage Research. 92: 69-78.

Derpsch, R. (2008). Keynote: Frontiers in conservation tillage and advances in conservation practice. In: [D.E. Stott, R.H. Mohtar, G.C. Steinhart, (Eds.)], Sustaining global farm. Selected papers from 10th International Soil Conservation Organisation Meeting held May 24-29, 1999 at Purdue University and USSA-ARS National Soil Erosion Research Laboratory.

Derpsch, R. and Friedrich, T. (2009). Global Overview of Conservation Agriculture Adoption. Proceedings, Lead Paper, 4th World Congress on Conservation Agriculture. 4-7 February 2009, New Delhi, India. pp. 429-438

Derpsch, R., Friedrich, T., Kassam, A. and Li, H.W. (2010). Current status of adoption of no till farming in world and some of its main benefits. International Journal of Agricultural and Biological Engineering. 3*:* 1-25.

Derpsch, R., Friedrich, T., Landers, J.N., Rainbow, R., Reicosky, D.C. and Sa., J.C. M., *et al*. (2011). About necessity of adequately defining no-tillage – a discussion paper. In Proc. 5th World Congress on Conservation Agriculture, 26-29 September 2011, Brisbane, Australia.

Dumanski, J., Peiretti, R., Benetis, J., Mc Garry D. and Pieri, C. (2006). Paradigm of conservation tillage. Proceedings of World Association of Soil and Water Conservation P1, 58-64.

Dumansky, J., Reicosky, D.C., Peiretti, R.A. (2014). Pioneers in soil conservation and Conservation Agriculture. Special issue, International Soil and Water Conservation Research March*.* 2(1): 1-4.

Erenstein, O. and Pandey, V.L. (2006). Impact of Zero-Tillage Technology, CIMMYT, Mexico.

FAO. (2008). Conservation Agriculture, 2008-07-08. Available at http://www.fao.org/ag/ca/index.html (verified 2/11/2013).

FAO. (2009). Conservation Agriculture. http://www.fao.org/ag/ca Rome, Italy

FAO. (2011a). Save and Grow, a policymaker's guide to sustainable intensification of smallholder crop production. Food and Agriculture Organization of United Nations, Rome. 116 pp.

FAO. (2012). Food and Agriculture Organization of United Nations, 2012. Available online at http://www.fao.org/ag/ca/6c.html.

FAO. (2014a). What is Conservation Agriculture? FAO CA website (http://www.fao.org/ag/ca/1a.html)

FAO. (2014b). CA Adoption Worldwide, FAO-CA website (http://www.fao.org/ag/ca/6c.html)

Farooq, M. and Siddique, K.H.M., 2014. (Eds.), Conservation Agriculture. Springer International, New York. ISBN 978-3-319-11619-8. DOI: 10.1007/978-3-319-11620-4. 3-20 pp.

Faulkner, E.H., (1945). Ploughman's Folly. Michael Joseph, London. 142 pp.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J. and S., Johnston, M., *et al*. (2011). Solutions for a cultivated planet. Nature 478, 337-342.DOI: 10.1038/nature 10452.

Friedrich, T., Derpsch, R. and Kassam, A. (2011). Global overview of spread of conservation agriculture, Presentation at Fifth World Congress of Conservation Agriculture, Brisbane, 26-29 September, http://aciar. gov. au/files/node/13993/global overview of spread of conservation agri 71883. (verified 2/11/2013).

Friedrich, T. and Kassam, A.H., (2009). Adoption of Conservation Agriculture Technologies: Constraints and Opportunities. IV World Congress on Conservation Agriculture. 4-7 February. New Delhi, India.

Fukuoka, M. (1975). One Straw Revolution, Rodale Press. English translation of shizennohowaraippeon no kakumei, Hakujusha Co., Tokyo. 138 pp.

Garcia-Torres, L., Benites, J., Martinez-Vilela, A. and Holgado-Cabrera, A. (2003). Conservation agriculture: environment, farmers experiences, innovations, socio-economy, policy. Kluwer Academic Publishers, Boston, USA.

Ghosh, P.K., Das, A., Saha, R., Kharkrang, E., Tripathy, A.K. and Munda, G.C., *et al*. (2010). Conservation agriculture towards achieving food security in north east India. Current Science 99(7): 915-921.

Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research. 114: 23-24.

Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A. and Sombatpanit, S. (2006). (Edn.), No-Till Farming Systsems. Special Publication No. 3. World Association of Soil and Water Association, Bangkok, Thailand. 66p.

Gonzalez-Sanchez, E.J., Ordóñez-Fernández, R., Carbonell-Bojollo, R., Veroz-González, O. and Gil-Ribes, J.A. (2012). Meta-analysis on atmospheric carbon capture in Spain through use of conservation agriculture. Soil and Tillage Research. 122: 52-60.

Haggblade, S. and Tembo, G. (2003). Development, diffusion and impact of conservation farming in Zambia. Food Security Research Project. Lusaka, Zambia: Michigan State University, Retrieved from: http://aec.msu.edu/fs2/zambia/wp8zambia.pdf.

Harrington, L. and Olaf, E. (2005). Conservation agriculture and resource conserving technologies – A global perspective. In Conservation Agriculture – Status and Prospects (Eds.), I.P. Abrol, R.K. Gupta, R.K Mallik. Centre for Advancement of Sustainable Agriculture, New Delhi, pp. 1-12.

Hobbs, P.R. and Gupta, R.K. (2003). Resource-conserving technologies for wheat in rice-wheat system. In Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts, ASA Special Publication 65: pp. 149-172.

Hobbs, P.R. and Gupta, R.K., (2004). Problems and challenges of no-till farming for rice-wheat systems of Indo-Gangetic Plains in South Asia. In: [R. Lal, P. Hobbs, N., Uphoff, D. O. Hansen, (Eds.)], Sustainable Agriculture and Rice-Wheat System.101-119). Columbus, Ohio and New York, USA: Ohio State University and Marcel Dekker, Inc.

Hobbs, P.R. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production. Journal of Agricultural Science. 145(2): 127-137.

Hobbs, P.R., Sayre, K. and Gupta, R. (2008). Role of conservation agriculture in sustainable agriculture. Philosophical Transactions of Royal Society B. 363: 543-555. doi: 10.1098/rstb.2007.2169.

Hubbard, R.K., Hargrove, W.L., Lowrance, R.R., Williams, R.G. and Mullinix, B.G. (1994). Physical properties of a coastal plain soil as affected by tillage, Journal of Soil and Water Conservation. 49: 276-283.

IIRR, (2005). International Institute of Rural Reconstruction and African Conservation Tillage Network. Conservation agriculture: A manual for farmers and extension workers in Africa.

IPCC. (2014). Climate Change: Synthesis Report. Contribution of Working Groups I, II and III to Fifth Assessment Report of Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.),]. IPCC, Geneva, Switzerland. 151 pp.

Jat, R.A., Sahrawat, K.L. and Kassam, A.H. (2014). (Eds.): Conservation Agriculture: Global Prospects and Challenges. CABI, Wallingford. 393 pp.

Karlen, D.L., Wollenhaupt, N. C., Erbach, D.C., Berry, E.C., Swan, J.B., Eash, N.S. and Jordahl, J.L. (1994). Crop residue effects on soil quality following 10 years of no-till corn, Soil and Tillage Research. 31(2-3): 149-167.

Kassam, A., Friedrich, T., Derpsch, R. and Kienzle, J., (2015). Overview of Worldwide Spread of Conservation Agriculture, Field Actions Science Reports [Online]. 8: 1867-8521.

Kassam, A.H., Basch, G., Friedrich, T., Shaxson, F., Goddard, T., Amado, T., Crabtree, B., Hongwen, L., Mello, I., Pisante, M. and Mkomwa, S., (2013). Sustainable soil management is more than what and how crops are grown. In: [R. Lal, R.A. Stewart. (Edn.)], Principles of Soil Management in Agro-ecosystems. Advances in Soil Science. CRC Press.

Kassam, A.H., Derpsch, R., Friedrich, T. (2014). Global achievements in soil and water conservation: The case for Conservation Agriculture. International Soil and Water Conservation Research. 2(1). 5-13.

Kassam, A.H. and Friedrich, T., (2009). Perspectives on Nutrient Management in Conservation Agriculture. Invited paper, IV World Congress on Conservation Agriculture, 4-7 February 2009, New Delhi, India.

Kassam, A.H., Friedrich, T. and Derpsch, R., (2010). Conservation Agriculture in 21st Century: A Paradigm of Sustainable Agriculture. European Congress on Conservation Agriculture. European Conservation Agriculture Federation (ECAF), 6-10 October 2010, Madrid, Spain.

Kavita Bhadu, Rakesh Choudhary, Tanuja Poonia, Payal Patidar, Choudhary, KM. and Kakraliya, S.K. (2018). A review paper on concept, benefits and constraints of conservation agriculture in India. International Journal of Chemical Studies. 6(4): 36-40.

Giller, K.E. andersson, J.A., Marc Corbeels., John Kirkegaard., David Mortensen, Olaf Erenstein, Bernard Vanlauwe. (2015). Beyond conservation agriculture. Frontiers in Plant Science. 6: 870

Lal, R. (2013). Climate-resilient agriculture and soil Organic Carbon. Indian Journal of Agronomy. 58(4): 440-450.

Lindwall, C.W. and Sonntag, B. (2010). (Edn.), Landscape Transformed: History of Conservation Tillage and Direct Seeding. Knowledge Impact in Society. Saskatoon: University of Saskatchewan.

Malik, R.K., Gupta, R.K., Singh, C.M., Yadav, A., Brar, S.S., Thakur, T.C., Singh, S.S., Singh, A.K., Singh, R. and Sinha, R.K., (2005). Accelerating Adoption of Resource Conservation Technologies in Rice Wheat System of Indo-Gangetic Plains. Proceedings of Project Workshop, Directorate of Extension Education, ChaudharyCharan Singh Haryana Agricultural University (CCSHAU), June 1-2, 2005. Hisar, India: CCSHAU.

Montgomery, D. (2007). Dirt: Erosion of Civilizations. California University Press, Berkeley.

Nath, C.P., Das, T.K., Rana, K.S., Bhattacharyya, R., Pathak, H., Paul, S., Meena, M.C. and Singh, S.B., (2017). Greenhouse gases emission, soil organic carbon and wheat yield as affected by tillage systems and nitrogen management practices. Archives of Agronomy and Soil Science. 63(12): 1644-60.

Negi, S.C. and Rana, S.S. (2016). Resource Conservation Technologies (RCTs)-Needs and future prospects: A review. Agricultural Reviews. 37(4): 257-267.

Nyathi, P., Mazvimavi, K., Kunzekweguta, M., Murendo, C., Masvaya, E. and Tirivavi, R. (2011). Assessing feasibility of mulching in mixed-crop livestock systems in Zimbabwe. Presented at: Conservation agriculture regional symposium for southern Africa, 8-10 February 2011, Johannesburg, South Africa.

Oyeogbe, A.I., Das, T.K. and Bandyopadhyay, K.K. (2018). Agronomic productivity, nitrogen fertilizer savings and soil organic carbon in conservation agriculture: efficient nitrogen and weed management in maize-wheat system. Archives of Agronomy and Soil Science. 64(12): 1635-45.

Pittelkow. C.M., Liang, X., Linquist, B.A., van Groenigen, K.J., Lee, J., Lundy, M.E., van Gestel, N., Six, J., Venterea, R.T., van Kessel, C. (2015). Productivity limits and potentials of principles of conservation agriculture. Nature. Jan 15: 517(7534): 365-8. doi: 10.1038/nature13809. Epub 2014 Oct 22. PMID: 25337882.

Piyush P., Ajay Verma and Mithlesh Kumar. (2018). Need of Conservation Agriculture in India: Sustainability. International Journal of Current Microbiology and Applied Science. 7(01): 308-314. doi: https://doi.org/10.20546/ijcmas.2018.701.033

Poddar, P.K., Miah, M., Uddin, M.N. and Dev, D.S. (2017). Conservation agriculture: A farm level practice in Bangladesh. Agricultural Science Digest-A Research Journal. 37(3): 197-202.

Pretty, J. and Bharucha, Z.P. (2014). Sustainable intensification in agricultural systems. Ann. Bot. 114: 1571-1596. doi:10.1093/aob/mcu205.

RWC-CIMMYT (2005). Agenda Notes. 13th Regional Technical Coordination Committee Meeting. RWC-CIMMYT, Dhaka, Bangladesh.

Sa, J.C., De Moraes., Burkner dos Santos, J., Lal, R., De Moraes, A., Tivet, F., Freire Machado Sá, M., Briedis, C., De Oliveira Ferreira, A., Eurich, G., Silva, A., and Friedrich, T. (2013). Soil- Speciic Inventories of Landscape C and N Stocks Under No-till and Native Vegetation to Estimate C Offset in a Subtropical Ecosystem; Soil Science Society of America Journal. Posted ahead of print 08/21/2013 (DOI:10.2136/sssaj2013.01.0007).

Sangar, S., Abrol, I.P. and Gupta Raj, K., (2005). (Edn.), Conservation agriculture: conserving resources and enhancing productivity. Conference report, 22-23 September 2004, Centre for Advancement of Sustainable Agriculture, New Delhi, p. 19.

Saturnino, H.M. and Landers, J.N. (2002). Environment and Zero-Tillage. APDC-FAO, Brasilia, Brazil UDC 504: 631/635, CDD 631.521.

Selvakumar, S. and Sivakumar, K. (2021). Conservation Agriculture: A Way for Soil Water Conservation. Agricultural reviews. DOI: 10.18805/ag.R-2045.

Sharma, A.R., Jat, M.L., Saharawat, Y.S., Singh, V.P. and Singh, R. (2012). Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. Indian Journal of Agronomy. 57: *(IAC Special Issue),* 131-140.

Stagnari Fabio, Solange Ramazzotti., Michele Pisante., (2009). Conservation Agriculture: A Different Approach for Crop Production Through Sustainable Soil and Water Management: A Review E. Lichtfouse (Edn.), Organic Farming, Pest Control and Remediation of Soil Pollutants, Sustainable Agriculture Reviews. 1 DOI 10.1007/978-1-4020-9654-9 5.

Sorrenson, W.J. and Montoya, L.J. (1991). Chapter about economics of tillage practices. In: R. Derpsch, C. H. Roth, N. Sidiras, U Kopke, 'Controle da erosão no Paraná, Brasil: sistemas de cobertura do solo, plantiodireto e prepare conservacionista do solo'. *GTZ, Eschborn*, pp. 165 -192.

Suraj Bhan and Behera, U.K. (2014). Conservation agriculture in India – Problems, prospects and policy issues International Soil and Water Conservation Research. 2 (4): pp. 1-12.

Tilman, D., Balzer, C., Hill, J. and Befort, B.L. (2011).Global food demand and sustainable intensification of agriculture. Proceedings of National. Academy of Sciences (USA). 108, 20260–20264. https://doi:10.1073/pnas.1116437108

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J. and Masso, C. (2014). Sustainable intensification and African smallholder farmer. Current opinion environmental sustainability. 8: 15-22. https://doi:10.1016/j.cosust.2014.06.001.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M. and Wall, P., (2010). Conservation agriculture, improving soil quality in sustainable production systems. In [R. Lal and B. Stewart (Edn.)]. Food Security and Soil Quality. Boca Raton, FL: CRC Press.

Vogel, H. (1995). Need for integrated weed management systems in smallholder conservation farming in Zimbabwe. Der Tropenlandwirt. 96: 35-56.

Wall, P. (2007). Tailoring conservation agriculture to needs of small farmers in developing countries: an analysis of issues. Journal of Crop Improvement. 19: 137-155.

Wassmann, R., Jagadish, S.V.K., Sumfleth, K., Pathak, H., Howell, G., Ismail, A., Serraj, R., Redona, E., Singh, R.K. and Heuer, S. (2009). Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. Advances in Agronomy 102: 91-133.

Wolff, P. and Stein, T.M. (1998). Water efficiency and conservation in agriculture – opportunities and limitations. Agriculture and Rural Development. 5(2): 17-20.