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Review Paper

Breeding wheat for yield maximization under conservation agriculture

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Abstract

Wheat based food security is being challenged due to declining profit, deteriorating production environment and changing climatic conditions. Conservation agriculture (CA) imbibing some components of the natural ecosystem can address some of these issues quite effectively. Wheat breeding so far, has managed to increase grain yield mainly by improving harvest index (HI) and adaptation through phenological manipulation. With limited scope for further increase in HI, an increase in biomass appears inevitable for wheat yield consolidation. The conflict between increased biomass and lodging that imposes a limitation to higher grain yield may have an answer in CA. The production environment under CA is much more congenial than conventional and hence offers an opportunity for identification of higher yielding genotypes. The article discusses the breeding issues and key traits for selection for yield maximization under CA. Integrating agronomic perspectives including cropping system, countering the tradeoff between stress adaptation and yield enhancement through management has been proposed. Selection indices build around increased coleoptile length, weed competitiveness, mild vernalization, increased duration and higher biomass could facilitate the development of CA adapted genotypes. These traits can be further fine-tuned according to different cropping and management practices.

Key words: Conservation agriculture, *Triticum aestivum*, plant breeding

Introduction

Wheat, being the most versatile and widely grown crop, is the mainstay of global food security. The demand for wheat in next 10 years is expected to grow rapidly in developing world due to a simultaneous increase in population and income (FAO WFP, I.F.A.D. 2013). The projected demand of 476 m tonnes of wheat in developing world by 2020 have to be met under the constraints of limited water and land for agriculture (Reynolds et al. 2011). Green Revolution technologies including improved varieties have played important role in increasing food production in India. Since the advent of the Green Revolution, India has been in a comfortable position regarding food production. However, with depleting ground water, degrading natural resources (Hira 2009; Rodell et al. 2009; Bhattacharyya et al. 2015) and fluctuating environment (Lobell et al. 2012; Semenov and Shewry 2011), food security net built around wheat is under challenge in the current century. Increase in frequency and magnitude of extreme events of weather may pose a serious challenge to wheat based food security. Earlier studies (Mitchell et al. 1993; Ottman et al. 2012; Tashiro and Wardlaw 1989; Wheeler et al. 1996) have estimated 3-10% losses in wheat yield with each degree rise in mean seasonal temperature. Warming pre pones the anthesis as well as maturity, thereby reduces the crop duration, kernel number per spike (Rahman et al. 2009), kernel weight (Gibson and Paulsen 1999; Rahman et al. 2009), HI (Prasad et al. 2008) and ultimately the grain yield. Plant growth stage around anthesis (Ortiz-Monasterio et al. 1994) is the most vulnerable in many crops including wheat (Jagadish et al. 2008; Prasad et al. 2000; Wheeler et al. 2000). Frequent occurrences of rare events like drought, coldness and flood have further compounded the problems. Wheat yield in Haryana in last seven years give the glimpses of the impacts of climate change on crop productivity (Fig. 1). The range of 1183

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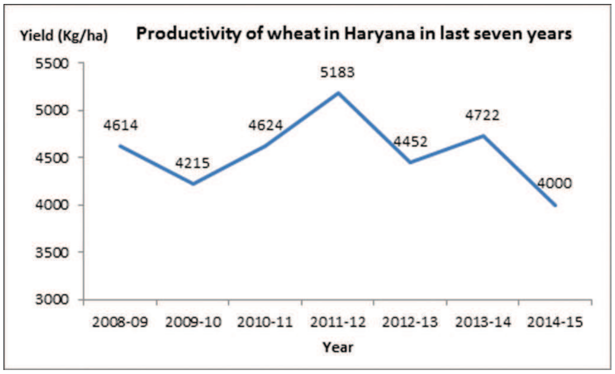

Fig. 1. Productivity of wheat in Haryana in last seven years

kg with standard deviation 379 kg in productivity over last seven years is quite large and makes a significant impact on food security if it is extended over two or three neighboring states simultaneously. The majority of wheat growing areas in India experience near or above optimum temperature for wheat growth particulary around grain filling stage, therefore, a slight increase in temperature will have very strong impact on yield. Moderation of crop development due to climatic changes can be countered to a large extent by either modulating the production environment through adoption of stress mitigating strategies or by selecting the varieties with appropriate flowering time and duration (Richard 2006). Moderation of temperature in and around crop canopy is central in both stress management strategies. Despite increased understanding of the timing of flowering under sub-optimal temperature condition, the overall response of crop plants under supra-optimal conditions is poorly understood (Craufurd and Wheeler 2009). Such understanding becomes important due to more frequent occurrence of extreme events under projected climatic change. The wheat growing seasons of 2014-15 and 2015-16 are reminders of such events. Under such conditions, designing of preemptive breeding strategies or production technologies become more complicated and difficult. Identification of phenological traits leading to yield improvement over the years can throw some light on the pattern of adaptation to changing climatic condition. Conservation agriculture practices encompassing crop rotation, minimum or no tillage along with residue retention can be an important intervention to modulate the extreme events like abnormally high temperature, a sudden downpour or even a moisture stress condition. The following section, therefore, will discuss the importance of CA and relevance of breeding of adapted genotypes to further consolidate the gain.

CA as a concept to address declining factor productivity, sustainability and climate change

The concept similar to present day CA was first time introduced by Edward Faulkner in 1945 and subsequently by Masanobu Fukuoka in 1978 in his book “One Straw Revolution”. The concept started picking up from Latin American countries in 1990’s and is now accepted globally as a sustainable agriculture practice. It is a resource-saving concept of crop production resulting in high production and more profit with minimum environmental footprints and, therefore, is sustainable. There has been a sharp rise in area under CA in Argentina from 300 thousand ha in 1991 to 22.3 Mha in 2008 (Trigo et al. 2009). It has also grown in India and covers 1.76 M ha (Erenstein 2009). Its adoption is slow due to various reasons, major being the knowledge gap on crop residue management, stand establishment under very heavy residue, appropriate agronomy including permanent bed, fertilizer placement and non-availability of adaptable varieties. Most of these changes are interrelated and the causal factors often have a complex interaction whichn poses great difficulty in prioritizing the breeding objectives.

Non-availability of CA adapted genotypes

In the beginning, CA promoted as zero-till technology could not find favors with farmers largely due to non-availability of proper machinery. Government initiative by introducing attachment of residue spreader in rice combine harvester along with the development of rotary seed drill have resolved the issue of seeding to a larger extent. Another challenge was the non-availability of CA adapted genotypes. Indications of genotype x management interactions have been reported in a number of studies (Joshi et al. 2007; Sagar et al. 2014a; Trethowan et al. 2005; Trethowan et al. 2012; Watt et al. 2005), and many times, contribution of such interaction to total variation is more than even the contribution of the main component. Large scale trials conducted by the senior author in the farmers’ fields even with limited wheat genotypes (HD 2733, HD 2824 and HD 2894) showed significant genotype x tillage interactions and mostly were of crossover type (Table 1). Despite such a proven gap hardly any public or private organization is working for the development of CA adapted genotypes. IARI, New Delhi, has taken the lead in initiating a full-fledged breeding program on wheat improvement for CA and the most of the projections made in the succeeding sections of the review are based on this experience.

Table 1. Response of released varieties of wheat under zero-till condition

Name of the genotype	Yield (t/ha)		
	Conventional	Zero/CA	Mean
HD 2894	4.615	4.324	4.4695
HD 2733	4.821	4.850	4.8355
HD 2824	4.465	4.105	4.285
Mean	4.633	4.426	
CD (Environment) @ 0.05	0.105		
CD (Variety) @ 0.05	0.129		
CD (var. x env.) @ 0.05	0.182		

Conservation agriculture production environment is different from conventional tillage in many ways (Wright and Hons 2004, Holeplass et al. 2004). Therefore, the varieties developed through selection under conventional tillage may or may not necessarily perform equally well under CA (Herrera et al. 2013; Joshi et al. 2007).

Learning from the past: Prevailing agronomy and cultural practices direct the breeding

Before Green Revolution, most of the wheat varieties grown in India were taller (more than 110-115 cm). Prevalence of taller landraces only despite reduced height being controlled by dominant allele at all three Rht loci and systematic experiment (Fischer and Maurer, 1978) proves adaptive advantages of height under uncertain moisture regime condition. These varieties had longer coleoptiles so that they can emerge from the deeper depth and exploit the available moisture. Taller varieties such as C 306, C 591 and a few of NP series cultivars, have the ability to cover the ground very strongly in the early phase and, therefore, accumulate enough of biomass with limited moisture. Many of traits like extensive root, tall stature and better ground coverage led to a better adaptation under moisture and temperature stress, but not necessarily higher yields (Blum 1996; Reynolds 2002). The introduction of semi-dwarf wheat based on mutation of *Rht B1* or *Rht D1* genes in the 1960s revolutionized the wheat production in entire South Asia, including India. The dwarf wheat varieties were lodging tolerant and provided an opportunity to apply more water and fertilizers. Partitioning of more assimilate towards sink in dwarf varieties improved the number of grains resulting in higher HI and yield. Continuous breeding efforts since the introduction of dwarf varieties have improved the yielding ability of wheat varieties in which duration of the crop also played important role. Longer duration, however, increased the probability of exposure to the terminal heat stress, resulting in strong fluctuation in production over the years. Development of higher yielding genotypes, thus, has been the response to the increased food demand and also favoured by improved the environment. Conservation agriculture, as it will grow, is also expected to create a demand of newer high yielding genotypes suiting new management environment. Genetic improvement for CA will be influence by genotype x management interaction. The presence of significant interaction for yield and quality traits and identification of QTLs accounting for substantial variation in the mapping population developed through CA and non-CA adapted genotypes substantiate the possibility of identification of CA adapted genotypes (Trethwon et al. 2012).

Characteristics of genotype adapted for CA

Longer coleoptiles and faster root development

As discussed in the previous section, deep planting was routinely followed in India before the introduction of dwarf varieties. Semi-dwarf, lodging resistant and efficient assimilates allocating cultivars, gave a scope for higher application of inputs and higher yield realization (Evans 1996; Miralles and Slafer 1995). Modern high-yielding cultivars grown in India have smaller coleoptiles, the structure which protects emerging seedling from the soil. These cultivars therefore could not establish well if sown deep and it becomes necessary to seed these at shallow depth. CA necessitates deeper seeding of wheat due to a presence of stubble, compactness in topsoil, un even top surface and penetrating tines of zero seed drill. For better stand establishment under CA, deep seeding of genotypes with alternate *Rht* gene (*Rht* 4, *Rht* 5, *Rht* 8, *Rht* 9, *Rht* 12, *Rht* 13) which retain sensitivity to GA and reduces plant height (Chen et al. 2013; Rebetzke et al. 2012, 2014) without affecting coleoptiles length may be required. Genotypes containing these alternate dwarfing genes have been reported to emerge well and establish a good crop under CA (Rebetzke et al. 2012). Modern Indian wheat varieties produce coleoptiles of around 70 mm length whereas the requirement under CA under Indian condition is slightly longer. Beside major genes affecting coleoptile length, there are QTLs with small and additive effects, identified on chromosome 1A, 2B, 2D, 3B, 3A, 5A, 6A (Rebetzke et al. 2007;

Spielmeyer et al. 2007) and these can be accumulated in the background of *Rht* 1 or *Rht* 2 through recurrent selection. In IARI, New Delhi, we have developed three genotypes of wheat adapted to CA. Genetic gain study was conducted by us on coleoptile length by studying the varieties released before and after Green Revolution indicates that lengths of coleoptiles after dipping very strongly during green revolution phase, have slightly improved, probably through the accumulation of minor genes as there is no major shift in *Rht* gene (Fig. 2).

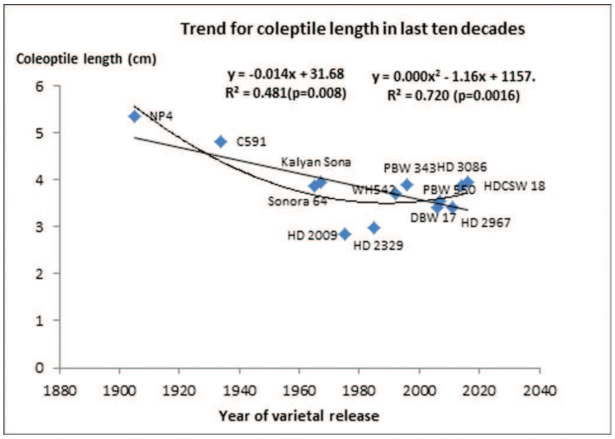

Fig. 2. Trend for coleoptile length for wheat varieties released in last hundred years

Similarly, the genotypes evolved through systematic breeding under CA have comparatively longer coleoptiles length with no major shift in *Rht* gene

It is important to note that beside coleoptile length, other factors like genetic background, crop residue load, temperature in the seed zone and light penetration (Allan et al. 1962; Botwright et al. 2001; Chastian et al. 1995; Jessop and Stewart 1983; Mohan et al. 2013; Nebreda and Parody 1977; Rebetzke et al. 1999) have profound effects on stand establishment. Seed size is another important trait, which has been reported to influence coleoptile length but only in tall durum lines (Trethowan et al. 2001).

Another important trait for CA adaptation is faster root development to enable rapid establishment by combating the initial harsh environment due to residue load, at least in the top zone of the bed and to take the best advantage of available moisture (Trethowan et al. 2005). In India, majority of the wheat area under partial CA is under rice-wheat cropping system, where rice is grown under tilled and puddle condition. Under such conditions, growth of the genotype with lower root biomass will be impacted under zero-till, at least during the early stage of plant life due to reduced nutrient mining (Joshi et al. 2007). Under full CA condition which can be easily integrated under maize-wheat cropping system, the regular input of organic matter through residue degradation increases biological activity in the soil and thereby soil's mineralization capacity (Singh and Bhogal 2014). The genotypes which can respond to this mineral availability through better biomass accumulation can bring yield enhancement. Better root system in terms of spread and depth is essential not only to establish active symbiotic relationships with beneficial organisms in the rhizosphere, but also for better anchoring of the plant so that it does not lodge in response to larger biomass. Deep seeding has a very strong conflict with the rate of tillering, tillering duration and number of tillers (Hucl and Baker 1990) in gibberellin insensitive genotypes. However, partial restoration of gibberellin response during coleoptile elongation by use of alternate dwarfing gene (Amram et al. 2015) or minor additive genes significantly reduce the impact of deep seeding on tillering. In contrast to this situation, there are areas in parts of Haryana, Punjab and Bihar which remains flooded (either because of poor drainage or large scale flood) at the time of wheat seeding and wheat seed is broadcasted in receding water to establish the crop early. Breeding has not been able to develop commercially successful cultivars for water logged conditions of wheat. However, inheritable variations have been exploited by Setters and Waters (2003) to develop waterlogged tolerant lines in Australia. Increased amount of aerenchyma has been linked with tolerance to water logging (Musgrave and Ding 1998) which can be further exploited.

Initial vigor/weed competitive genotypes

Under zero tillage, weed seeds produced by the weeds in the previous seasons remain in the top layer and therefore germinate with the availability of moisture and suitable temperature regime. Therefore, weed intensity in the absence of suitable pre-sowing weed control is likely to be more in the initial years of zero tillage. It is, therefore, very important that the genotype for the zero-till condition should also have high vigor with large foliage and good stand establishment, so that it out-competes the weeds. Development of GA-responsive genotypes could also improve early vigour and thereby weed competitiveness (Amram et al. 2015; Rebetzke et al. 2012).

Genetic nature of weed competitiveness of wheat varieties has been established (Cosser et al. 1997; Lemerle et al. 2001; Wicks et al. 2004). Yield reduction under same weed infestation across wheat varieties varies from 17-62% (Balyan et al. 1991) and indicates the presence of weed rate x genotype interaction (Huel and Hucl 1996). In one study, weed competing ability of wheat genotypes led to a yield gain of 7–9% (Hucl 1998). However, there has been a lesser emphasis by breeders on the selection of weed competitive genotypes (Murphy et al. 2008) due to better availability of chemical herbicides. Some of the genotypes (such as HDCSW 18 and HD 3117) that were selected under CA, possessed spreading to semi-spreading growth habit, superior seedling vigour and were single dwarf (100 to 110 cm).

Mild vernalisation requirement for yield consolidation

In the last 50 years, only few varieties (called mega varieties) covered a huge area in India especially North Western plains Zone (NWPZ) (Yadav et al. 2010). The first mega variety was Sonalika, followed by Kalyan Sona, HD 2329, PBW 343 and HD 2967 over years. Interestingly, except for Sonalika, more recent varieties showed delayed heading and maturity (Figs. 3 and 4). However, increased duration without any significant adjustment in date of seeding increased the probability of exposure of crop to terminal heat stress especially in Haryana, western UP, and Rajasthan where mean temperatures are relatively higher than optimum. In Punjab, most areas have longer winters and therefore showed lesser yield fluctuations. The terminal stress can be escaped by early sowing which is more feasible under CA since it ensures more moisture in the topsoil.

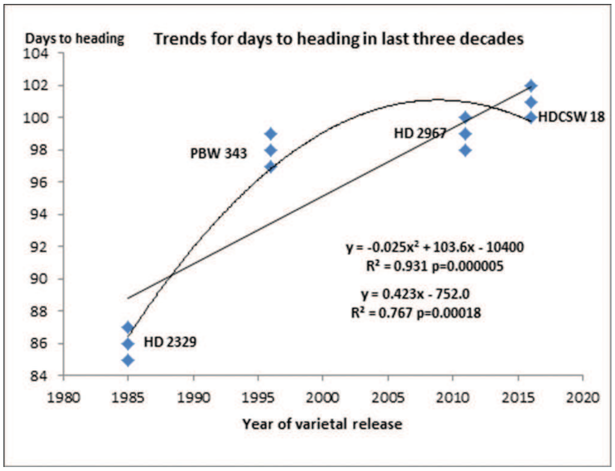

Fig. 3. **Trend for days to heading in three mega varieties and recently released variety for CA (HDCSW 18) from 1985-2016**

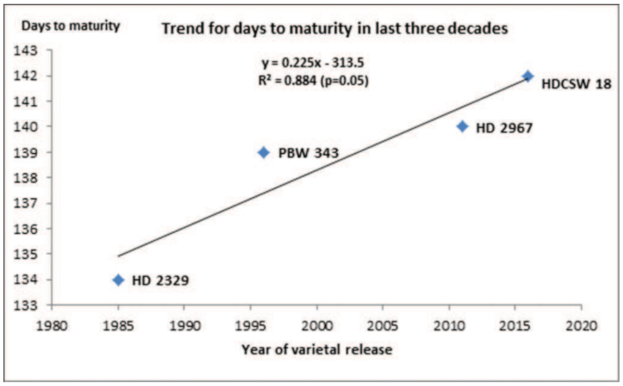

Fig. 4. **Trend in total crop duration in three mega varieties and recently released variety for CA (HDCSW 18) from 1985- 2016**

As CA reduces the turnover time between crops, early (October) sowing is feasible in most cropping systems including the predominant rice-wheat in Indo-Gangetic plains of India. Availability of zero-till seeding machine, like “happy seeder” has made it feasible to establish wheat early with conserved moisture. Phenological adjustment through vernalisation (Vrn) and photoperiod (Ppd) genes have played important role in adaptation of wheat crop (Law and Worland 1997). Among the three *Vrn* genes, *Vrn-1* (*Vrn-A1, Vrn-B1 and Vrn-D1*) have been used widely along with *Ppd* genes. *Vrn-A1a* completely eliminates vernalisation requirement while increased expression of the *Vrn-D1* through *Vrn-D1a* contributes to early flowering and maturity (Zhang et al. 2015). Varieties with dominant alleles at all three *Vrn-1* loci (*Vrn-A1a*, *Vrn-B1a*, *Vrn-D1a)* and other combinations of *Vrn* alleles lead to very early flowering in response to degree days. Early heading reduces tillering capacity as well as number of spikelet per head in many genotypes, like HD 2851 and HD 2329 and reduces yield. On the other hand, many genotypes like PBW 343, HDCSW 18, HD 2967 and CSW 57 do not head early in response to accumulated degree days in early seeding, probably because of mild vernalisation requirement (Fig. 5). All of these genotypes, therefore, can be seeded early without any yield penalty. HDCSW 18, a product of systematic breeding for CA, is highly suited for early seeding and out-yielded major varieties of NWPZ in multi-location trial (Fig. 6). We have observed that yield gain through higher biomass and delayed heading/

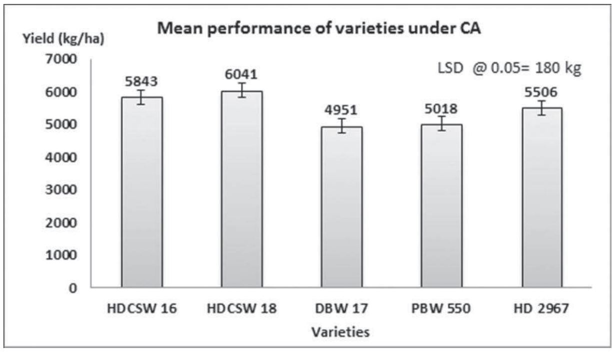

Fig. 6. **Mean of performance of varieties bred for CA (HDCSW 16 and HDCSW 18) and commercial checks from ten locations over two years under early seeding of C**

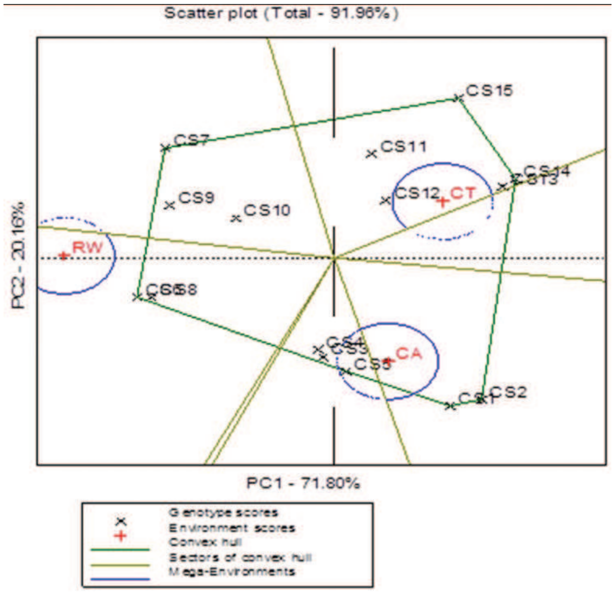

Fig. 7. **GGE biplot view of 15 genotypes developed and evaluated in different cropping system/ agronomic practice**

longer duration under early seeding of CA can be realized through varieties having mild vernalisation requirement.

Integrating cropping system and agronomy perspective in breeding for CA

Gain in wheat productivity will be very hard to come by in near future particularly under the constraint of degrading production environment. By exploiting the genotype x management interaction, yield gain can be consolidated in the future without adversely affecting the environment. CA can reverse many of soil problems generated by unsustainable and environmentally unsound crop production technologies. Under conventionally tilled condition with high nutrient supply, genotypes with high tillering and strong head (and thereby with higher biomass) do not necessarily yield higher, either because of lodging or poor translocation of assimilate toward the end of the cropping seasons (due to abrupt heat stress). Under zero-till condition, probably we can exploit all these traits for higher yield realization. Most of the genotypes under permanent beds produce a slightly higher number of tillers and more number of florets, because of increased number of fruiting nodes per spike that result in more number of grains per ear (Mulvaney et al. 2014). Earlier studies failed to detect genotype × tillage practice interactions (Dao and Nguyen 1989; Ditsch and Grove 1991), likely as a result of the small number of genotypes tested and perhaps due to the fact that they were bred under conventional tillage (Trethowan et al. 2005). Recently, significant genotype × tillage interactions were reported in tests involving diverse genotypes, indicating the need for dedicated breeding programmes to tailor cultivars to tillage systems (Erenstein 2002; Klein 2003; Mulvaney et al. 2014; Sagar et al. 2014b; Trethowan et al. 2012; Yadav et al. 2011; Gupta and Yadav 2014). Changing varietal scenario in other crops in the wheat-based cropping sequence particularly in rice-wheat is influencing wheat varietal dynamics. Designing of production technologies including variety, which can be integrated easily in the prevalent cropping system will encourage the farmers to invest for long term reward. One such integration can be permanent raised bed techniques in maize-wheat-moongbean (*Vigna radiata* L.) cropping system. There are a number of advantages of this technique holistically (Bhattacharya et al. 2013). Lodging is a recurring issue particularly under more productive environment and favorable seasons for crop growth. The high productivity base set due to profuse tillering and better growth remains largely unrealized either because of more lodging under flat bed planting with flood irrigation or due to water stress as farmers skip the crucial last irrigation (Abrol 1999) to avoid lodging. Bed planting a water saving and lodging avoidance technique (Sayre 2002) could not be realized under Indian condition due to machinery issue, slightly higher incidence of termite along with water stress at the terminal stage. However, many of these issues can, not only, be effectively addressed by permanent bed techniques but also can easily be integrated in maize-wheat or pearl millet-wheat cropping system and can lead to higher yield realization both in maize(avoiding flooding during monsoon) and wheat

Fig. 5. CSW 57 (in the centre of photograph), a weed competitive and mild vernalization requirement genotype highly suited for early seeding under CA

Fig. 8. An early direct seeded crop of HDCSW 18 under CA at farmer's field in Haryana

Fig. 9. HD 3117, the genotype with weed competitiveness and efficient water use for CA

(avoiding lodging and improving water use efficiency under water limiting conditions). Permanent bed with higher water percolation rate better drainage, lesser crust formation will be more helpful in better stand establishment for Kharif crops. Significant genotype x planting system interaction (Tripathi et al. 2005) can be effectively harnessed by integrated system perspective in breeding. Breeders must keep cropping system and smart agronomy while developing the varieties. A directed breeding programme to develop wheat genotypes adapted to different cropping systems *vis-a-vis* their agronomy at IARI shows specific adaptation under GGE biplot analysis (Fig. 7). GGE biplot clearly differentiates rice-wheat (RW; partial CA), maize-wheat (MW; CA) and conventional tillage (CT) by the obtuse angle between environment vectors. It was also interesting to note that under GGE analysis, genotypes were found to specifically pool with their selection environment. The preceding crops under CA (tillering or non-tillering) influence the agronomy to be followed under wheat and different agronomy requires different wheat genotypes. Therefore, to make a further gain in productivity, designing CA-based agronomy for specific cropping system and evaluating the breeding material under such environment can yield fruitful results. We found some traits leading to specific adaptation of wheat were slightly taller height, high tillering and increased biomass for maize-wheat under CA, slightly tall, reduced tillering (less tiller death) with increased grain sites and higher biomass in rice-wheat and moderate height and moderate biomass under CT. Shifting toward short duration variety of basmati rice like PB 1121 and PB 1509 in rice-wheat belt offers an opportunity ti exploit an extra period of 20-30 days for yield maximization in wheat. Genotypes with mild vernalization requirement, high biomass, strong stem and good sink capacity can further maximize wheat yield. A recently released wheat variety, HDCSW 18 for CA meets all of this criterion and gives significantly higher yield if seeded early. In wheat crop sown at less density, up to 75% of tillers die before flowering (Mitchell et al. 2013).

Increasing the biomass and improving the sink

Wheat yields in many growing regions of the world have stagnated (Brisson et al. 2010). However, there are no indications that genetic yield potential in wheat has reached to a plateau (Manes et al. 2012). Past gains in wheat yield have largely come through improved HI while potential HI (0.5-0.6) has already been realized. Hence, future gain by genetic manipulation can come through by increasing biomass

(Curtis and Halford 2014; Parry et al. 2010). Biomass can be increased by a number of ways such as increasing the photosynthesis per unit leaf area, increasing crop duration and by improving the crop canopy. Most of the cereal crops including wheat are not limited by source and therefore, opportunities exist for improving the sink strength by increasing the assimilate allocation toward reproductive primordia more particularly distal florets (Guo et al. 2016; Richards 2000). Wheat breeders have exploited most of the traits for higher biomass production and better assimilate allocation. However, higher biomass leading to higher yield is restricted due to lodging especially under high input production environment. Under CA there is reduced lodging due to faster water percolation and better plant anchorage. Therefore, wheat breeders can exploit improved production environment like CA to identify more high yielding genotypes with higher biomass.

Countering the tradeoff between stress adaptation and yield enhancement

Climate change generally happens at a slow pace and hence is difficult to predict the its overall effect. The climate changes induced stresses can be handled by a combined approach of developing stress adaptive varieties and manipulating production environment. Combining stress adaptation along with yield improvement needs pragmatic approach. Breeding for earliness can help escape water and temperature stress at the terminal stage but may be counterproductive for grain yield. In crops like maize, yield improvement happened because of the synergistic effect of yield potential and availability of better resources (Duvick and Cassman 1999). Generally enhanced yield potential require better resource, particularly water, which may not be fully available in future. Conservation agriculture practices are more appropriate under climate change scenario. If stress is managed through good management practices, longer duration varieties of wheat and hybrids of maize could be more rewarding. In the field maintained under CA for last seven years at IARI, we are able to seed maize immediately or a day after light to moderate rainfall (10-60 mm) and within two-three days in case of heavy a downpour (100m). Maize seedlings on slightly raised permanent bed during monsoon also escape drowning in case of heavy rain. When monsoon is poorer, residues in furrow protect water loss and ensure longer moisture availability. Conservation agriculture, therefore, provides more opportunity for cropping intensification and increasing yield potential. Permanent raised beds (PBs), with residue retention are gaining adoption due to higher water use efficiency, better plant establishment and comparatively better yield over zero till flat and CT (Boulal et al. 2012; Govaerts et al. 2005; Tursunov 2009; Yadav et al. 2011). The permanent bed can increase water productivity by 25-40% in irrigated agriculture (Akbar et al. 2007; Hassan et al. 2006; Sayre and Hobbs 2004). Surface mulch through previous crop residue, which reduces evaporation losses (Lal et al. 2007) and increases soil water retention capacity (Gant et al. 1992) can easily be integrated into permanent bed system However, in most of the northern India, pearl millet and maize are grown on flatbed during monsoon season and therefore, no information is available for the response of the genotypes on raised bed. Our limited experimentation has shown very less genotype × sowing method interaction in maize but large in the case of pearl millet. There exists an opportunity to exploit such genetic variation in pearl millet.

In trials conducted during last five years on maize under maize-wheat cropping system, we have tested a large number of hybrids of different maturity group under CA as well as CT and found little difference in yield in early maturing genotype. However, yields were significantly higher under CA for longer duration maize hybrids. Thus CA provides an opportunity for yield maximization through breeding in crops like pearl millet and maize.

Extending benefit of CA through water and nitrogen use efficient genotypes in wheat

Irrigation is the most vital input for increasing food production globally and sustainability concerns along with second-generation problems of intensive agronomic practices like silting and accumulation of salt constrain the further expansion of irrigation (Araus et al. 2008). Conservation agriculture practices such as permanent bed and residue retention through reduced evaporation losses, increased water infiltration and better water retention, increase the amount of plant-available soil water (Jat et al. 2011; Lal et al. 2007; Wiatrak et al. 2005). WUE can further be improved by directing the breeding programmes to exploit the existing genetic variability for three key processes: moving more water through the crop, building more biomass per unit of water transpired and better translocation of assimilate toward sink (Condon et al. 2004).

Table 2. Yield performance of HD 3117 under late sown condition of conservation agriculture at two sites

Name of the variety	New Delhi yield (q/ha)				Shikopur (Haryana) yield (q/ha)				Overall mean (q/ha)	Gain
	2010-11	2011-12	2012-13	Mean	2010-11	2011-12	2012-13	Mean		
HD 3117	48.50	46.60	50.10	48.4	44.30	48.60	49.20	47.37	47.88	
WH 1021	45.30	42.30	44.60	44.1	42.60	43.70	44.10	43.47	43.77	9.390
HD 2932	42.20	43.10	46.50	43.9	41.10	44.10	42.30	42.50	43.22	10.782
DBW 17	42.60	44.50	41.10	42.73	38.50	45.20	36.50	40.07	41.40	15.652
CD 0.05	3.95	2.69	2.59		2.52	1.91	2.99			
CD 0.01	5.68	3.87	3.71		3.62	2.74	4.29			
SE	1.74	1.19	1.14		1.24	0.71	1.74			
CV	5.53	3.82	3.55		3.79	2.63	4.34			

Better root architecture to explore more water from deeper soil profile, along with semi-spreading to spreading growth habit as in cv. HD 3117 to reduce evaporative losses along with weed suppression and longer coleoptiles can simultaneously improve water use efficiency and increased adaptability to CA (Table 2 and Fig. 9).

Besides water, nitrogen (N) is highly limiting under irrigated crop production of Asia (Ibragimov 2007). N dynamics under CA can vary considerably (Anga´s et al. 2006; Limon-Ortega et al. 2000). Inability to place N fertilizer deeply in the in presence of heavy residue load, high C/N (Carter and Rennie 1984) ratio and initial N immobilization (Hutchinson et al. 1995) results in lower crop N-use efficiency at least during early stages of CA. However, re-mineralisation of N (Karlen 1990) in subsequent years Dalal et al. 2011) and use of Turbo Happy Seeder for deep placement of larger portion of N (Sidhu et al. 2007) can greatly improve the NUE. Under irrigated ecosystem, nitrate is readily leached along with irrigation water. The primary root traits which have sufficient genetic variation in the germplasm and are in synchrony with WUE include root length, root biomass, root density, lateral root dispersion and can be directly selected (Cormier et al. 2016; Foulkes et al. 2009; Hurd 1964). In wheat, the use of synthetic wheat derivatives may help in the development of cultivars with relatively deeper rooting systems. Synthetic with genes incorporated from *Triticum tauschii* (Reynolds et al. 2007), IB/IR carrier lines from CIMMYT along with many landraces from China and Iran (Ehdaie et al. 2003) are reported to have increased root biomass at depth. Large influence of production environment on the expression of these traits, their polygenic inheritance and difficulty in large scale phenotypic scoring, however, limit their use in the breeding programme. Cromier et al. (2016) have rightly summarized that breeding for enhanced NUE can be achieved through the use of increasing information generated by throughput genotyping and phenotyping.

Conclusion

Conservation agriculture as a component of precision agriculture package has not been fully appreciated by farming communities in India. However, depleting natural resources and changing climatic conditions is expected to bring this technology to the forefront. Among Green Revolution technologies, improved varieties have been the most appreciated and still can act as a fulcrum for the adoption of CA. Directed breeding toward agronomy including CA and cropping system have shown promise with two varieties released in India for cultivation under CA. Conservation agriculture, therefore, offers opportunity for further yield maximization through breeding.

Declaration

The authors declare no conflict of interest.

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