REVIEW OF LITERATURE
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REVIEW OF LITERATURE

2.1 Triticale history

Triticale, a probable future man-made hybrid cereal crop with high genetic potential, has attained some commercial value within the time span of little over 100 years since its origin as compared to wheat which took thousands of years for its evolution and establishment in nature. Credit should go to Stephen Wilson, a Scottish research worker, who in 1875, reported the first successful cross between wheat and rye during the transaction of Edinburgh Botanical Society after dusting the emasculated pollens from rye plant upon the stigma of wheat. However, the few seeds so produced germinated and developed as sterile plants. Just after a decade or so, the first fertile and true breeding triticale was reported by a German breeder, Rimpau in 1891. Because of low fertility and difficulty in obtaining viable seeds, this hybrid remained an academic curiosity for few more decades. It started again in 1918, when thousands of natural hybrids appeared in wheat fields at Saratov Research Station (Russia). After passing through several generations, true breeding more or less fertile derivatives were developed by Meister (1921) and exploited these hybrids for several years. Later, Müntzing in 1934 at Svalov, Sweden, initiated exhaustive research on triticale and continued it for many years. Significant breakthrough ultimately was made by Pierre Givaudon in 1937, by treating the sterile seedlings with colchicine, which resulted in production of fertile triticales by doubling their chromosomes. This thrilling discovery together with embryo culture techniques developed in 1940, opened the door for the development of triticale as a potential grain crop (Briggle, 1969; Hulse and Spurgeon, 1974; Müntzing, 1974; Zillinsky, 1974; Inam, 1992; Varughese et al., 1996a, b).
In 1947, triticale improvement programme was started in Hungary followed by some other countries of Europe and North America. Extensive and productive triticale research programme was undertaken at the University of Manitoba, Canada and CIMMYT (Mexico), which was the beginning of today’s triticale. This programme had started in 1954 with the establishment of Rosner research chair at Manitoba. The triticale that had originated here showed remarkable hybrid vigour in Mexico. Unfortunately, it was late maturing, tall and bearing sterility. However, between 1959 and 1962, due to extensive crossing among more fertile primary triticales, some secondary triticales were produced. By 1967, new cultivars of triticale were developed which recorded yield as high as standard cultivars of bread wheats in the Western Canada. Therefore, for modest production, at Manitoba, the selected cultivars were grown under contract for fermentation and distilling industries. Some of the new cultivars also showed high potential as fodder crop. By 1969, a new cultivar of triticale “Rosner” was released for commercial purpose in Canada.

CIMMYT (Mexico) in 1969, initiated the programme at international level for testing the triticales. The first International Triticale Yield Nursery (ITYN) was grown in 1969-70 at different locations. Since then, ITYNs were continuously conducted all over the world including Aligarh (India) under varied agroclimates. Data recorded from these nurseries indicated that triticale which was lagging behind wheat and other cereals in earlier trials has now almost completely outyielded them in many agroclimatic conditions.

The first International Triticale Association was established in 1986 and in the same year first triticale symposium took place at Sydney, (Australia). It was for the first time when merits and demerits were discussed by researchers involved in triticale research. This raised the interest in the mind of people for cultivating triticale as a new crop in their field. Therefore, in 1987, Poland became the first largest country where triticale was cultivated on an area of
about 6,00,000 ha. The 2nd and 3rd International Triticale Symposia were organised at Passo Fundo (Brazil) and Lisbon (Portugal) during the years 1990 and 1994 respectively (Varughese, et al., 1996a, b). There were no definite reports on acreage and production of triticale world wide. However, mention may be made of Hulse and Spurgeon (1974) who reported an acreage of about 4,00,000 hectares in 52 countries while another report appeared (Anonymous, 1982) for about 5,00,000 hectares under triticale cultivation. From European belt, nearly 5,00,000 hectares of land was estimated under triticale production with major cultivation in France (Suijs, 1986). More recently Varughese et al. (1996a, b) gave an estimated area of 2.5 million hectares under triticale cultivation all over the world with an estimated production of six million tonnes.

2.2 Nomenclature

Triticale – as hybrid of wheat and rye, expectedly showed resemblance morphologically in one way or the other with both the parents. However, it must be admitted that it resembles wheat more than rye due to the dominance of wheat traits, but possess more vigorous growth than either parents. There was no general agreement among the taxonomists regarding the naming of this hybrid cereal, and it remained a taxonomical problem. Thus, different names have been suggested from time to time. Mention may made of Tschermak and Bleier (1926) who suggested the name as “Aegilocale” for an Aegilops × Secale hybrid and “Aegilotricale” for hybrid combining three genera Aegilops, triticum and Secale. Later on, “Aegilotriticale” was used by Leighty and Sando (1927) to indicate the clear presence of Triticum. The name “Triticale” coined from prefix of Triticum (wheat) and suffix of Secale (Riley and Chapman, 1957), appeared in the scientific literature for the first time in 1935. Credit may go to Tschermak, one of the rediscoverers of Mendelian work (Lindschau and Oehler, 1935). Larter et al. (1968) suggested two names as “Triticale hexaploide” and “Triticale octaploide” as a specific name for 42 and 56
somatic chromosome forms, respectively. In 1966, Kiss proposed “Triticum Triticale” as a designation for hexaploid triticale.

Later, Baum (1971) suggested another name “XTriticosecale Wittmack” as an accepted scientific nomenclature for triticale. However, McVaugh (1973) subsequently reported that the conservation of Triticale was recommended because the name has become well known as the “generic” name for hybrids between Triticum and Secale. Zillinsky (1974) argued that triticale should be placed under the genus “Triticum” on the basis of precedent and genomic relationship. While Baum and Gupta (1990) made strong argument to elevate triticale to generic status and provided a key for distinguishing genera Secale, Triticum, Aegilops and XTriticosecale. At present, XTriticosecale Wittmack though recommended for continuous usage by Stace as mentioned by Varughese et al. (1996a), for the sake of general acceptability and popularity, the name “Triticale” will be used in the present thesis.

2.3 Types

Based on the historical development, Müntzing (1979) classified triticale into five types:

1. Primary triticales
2. Recombinant secondary triticales
3. Secondary triticales
4. Substitute triticales
5. Secondary substitute triticales

Gupta and Priyadarshan (1982) classified triticale into two types:

1. Primary triticales – as a raw amphiploids derived from Triticum and Secale genera. They contain all seven pairs of rye chromosomes.
2. Secondary triticales – as a stable derivatives from intercrossing primary (hexaploid and octaploid) triticale, wheat, rye and other secondary triticales.
According to National Research Council (1989), two major types of hexaploid triticales were commercially grown: ‘Complete’ and ‘Substituted’. Complete triticale contains in addition to the “A” and “B” genomes of wheat (*Triticum turgidum*) all seven pairs of chromosomes from rye (*Secale cereale*) whereas in substituted triticales, the rye chromosome 2R has been replaced by chromosome 2D of hexaploid wheat (*Triticum aestivum*). Varughese (1991) distinguished two types of triticales according to their growth habits; winter triticales, which needs vernalization for floral differentiation and spring triticales, which does not need vernalization. Varughese et al. (1996a), on the basis of ploidy level and genomic composition further classified triticales into:

1. Tetraploid triticale (2n=28), whose genomic composition can be AABB, DDRR or a balanced mixture of A, B, D and R genomes.
2. Hexaploid triticale (2n=42) which was an amphiploid resulting from cross between wheat (*Triticum turgidum* L.) and rye (*Secale cereale*) with a genomic composition AABBRR. The hexaploid triticales were extensively used triticale forms all over the world including at CIMMYT yearly triticale trials.
3. Octoploid triticale (2n=56) has a genomic composition of AABBDDRR and was the result of cross between wheat (*Triticum aestivum* L.) and rye (*Secale cereale*).

2.4 Adaptations

Every individual plant or species try to adapt itself by adjusting to the surroundings. It may be limited in its distribution or range widely over broad area of physical environments in search of space, nutrients and moisture for survival, growth and development. Thus, the plants may be affected by various physiological, biological, chemical and physical factors. Therefore, each plant must be fairly and accurately adjusted to its habitat, at least in that it surpasses certain minimum adaptational requirements. Finlay and Wilkinson (1963) stated that “adaptability can be measured in quantitative way through
calculations involving average grain yield of many varieties". Oka (1967) classified adaptations into two classes, general and special. General adaptation is a complex genetically determined characteristics which makes high stable yields possible under different ecological conditions. On the other hand special adaptation as a tolerance to specific conditions. While Matsuo (1975) defined adaptation as a “capacity of genotype to give high and stable yields under different environmental and cropping conditions and in different years”. According to Beeby (1995), the species may be abundant in a particular region when the conditions for its growth and reproduction are optimum.

Triticale showed a wide range of adaptation over different as well as adverse agroclimatic conditions. Being hybrid of wheat and rye, contribution with regard to adaptation and yield potential has been received from both the parents. It is known for its high potential yield due to ‘A’ and ‘B’ genome of wheat and adaptation to relatively dry environments. On the other hand, rye, the ‘R’ genome donor has comparatively lower yields but is more adapted to extremes like cold, drought and acidic soils in addition to others.

The interest among the researchers of this cereal in recent years resulted in developing new cultivars, which have good level of adaptations to climatic and soil conditions and their effective utilization of even low levels of mineral nutrients. These new cultivars are more adapted to suboptimal environmental factors, specially these are tolerant to low soil pH as well as salinity and high aluminium concentrations (Qualset and Guedes-Pinto, 1996). Due to the inherent problems in earlier periods, selection pressure to fit triticale to many ecological conditions had not been involved as with other cereals. Thus, the genetic base remained narrow, which limited its adaptation to different latitudes, elevations, temperature extremes, day length and other factors. Thus, remained dependent on the limited variation present within its component genomes (Anonymous, 1972). For getting broader adaptations, there was a need to widen the germplasm base. This process was further accelerated by the
The CIMMYT collaborative network of cooperative testing with wide spread international programmes.

The regular additions and integration of new germplasm had completely changed the adaptive nature of triticales very fast. Hence later released cultivars were found in close competition with wheat and other cereals at many locations including Aligarh. Many others were generally adapted to rather broad regions and still others were ill adapted in most locations. However, improvement was significantly rapid and consistent. The percentage of the locations in which triticale cultivars ranked among top five yielding cultivars including wheat check consistently advanced from 11.3% (1969-70) to 13.8% (1970-71) and to 16.3% (1971-72). In case of triticale, where it outyield wheat ranged from 1% to 6% (Anonymous, 1972).

With the introduction of Armadillo strains in the international trials during 1969-72 and two gene dwarf triticales in 1972-73 trials, further improvement was noticed in both yield as well as adaptation. The dwarf cultivars were particularly less affected by the lodging problem, which was frequently observed in earlier triticales (Zillinsky, 1974). Break through in this regard was observed during the 5th ITYN, where triticale outyielded the wheat check. A steady upward trend in adaptation had thus been observed since then (Anonymous, 1976b).

Trials conducted at Toluca (2600m elevation) showed that triticales were more competitive with wheat than at Yaqui valley of Sonora (Mexico), 35m elevation (Zillinsky, 1974). In Mexico, performance of 60 octaploids and hexaploids was studied by Martin and Maurer (1973). It was found that hexaploids showed comparatively better performance than octaploids and were also higher in yield than wheat. Similar type of studies were carried out by Dorofeev and Kurkiev (1975) and Pavlov et al. (1976).

The International Triticale Yield Nurseries (ITYNs) conducted since 1970, provided evidence of broadening its adaptation base to diverse
environment conditions. The transfer of insensitivity to day length from Mexican bread wheat to triticale has improved its adaptation within the regions of low latitude (30°N to 30°S). In higher latitude locations in Northern Hemisphere, such as, Sweden, Poland, Quebec province in Canada, triticale appeared to be less adapted than the best local wheat checks (Anonymous, 1978). The practice of growing two crop cycles a year in Mexico under various agroclimatic conditions had significantly improved the adaptive nature of Mexican triticales. This change of environmental factors permitted the identification of some strains which were light insensitive, resistant to diseases and having high yield potential. Several triticale strains like “Mapache”, “Beagle”, “Rahum” and “Bacum” were placed under broadly adapted class. The results of the nurseries conducted during 1977-78 indicated that triticale showed greatest competitive advantage in at least three regions of developing nations; the hill areas of India, Pakistan and also the Nepal, the East African highlands from Ethiopia to South Africa and the Southern cone countries of South America particularly the Brazil and in Columbia to the North (Anonymous, 1979b).

Results from the international triticale trials showed an improving trend in the adaptations particularly in the acidic soils and cool high lands where triticale has 100% production advantage over wheat (Anonymous, 1980). In India, Gill and Sandha (1980) introduced new triticale cultivar “TL419” (Triticale Ludhiana 419) in Punjab and released it for commercial cultivation. It performed well under local conditions of Punjab. Later on, many cultivars were released in India from Punjab and Pantnagar, (Uttar Pradesh).

In the eleventh ITYN (1979-80), Triticale cultivars Beaguelita ‘S’ and Ram ‘S’ out yielded the wheat check Pavon ‘76’ across many locations (Africa, America, Mexico, Poland, etc.). The higher dry matter production of triticales may push it to higher yield potential than what may be obtained in wheat. However, late maturity and preharvest sprouting were problems associated with
it, which delayed its acceptance in places where conditions at the harvest were moist. CIMMYT undertook these problems in collaboration with INIA scientists and improvement had been observed. With this, cultivation of triticale enhanced particularly in developing countries (Anonymous, 1981). May (1981) reported the performance of triticale cultivars in New South Wales since it started in 1974. The cultivars were tested on fertile soils with pH 5.8 and on acidic soils with pH 4.3. On such soils, it showed more adaptation and production than wheat and barley due to difference in their Al tolerance.

Triticale being known to adapt under adverse environmental conditions, showed remarkable performance under treated effluent too by outyielding the wheat (Aziz, 1991, 1994). Similar type of studies on five cultivars of triticale were carried out by Shah (1995) under sewage wastewater irrigation where triticale showed high adaptation in terms of growth and yield. More recently, Tarannum (1998) confirmed the superiority of triticales at Aligarh by conducting trials under different soil applied potassium doses.

One of the main objectives of the CIMMYT triticale programme was to produce triticales, which can be grown in areas of the world where wheat performed poorly like in acidic soils of Brazil. These triticales were intended for use as both feed grains as well as food for human consumption. In the 16th ITSN, complete and substituted triticales were tested for various quality parameters like grain plumpness, test weight, alpha amylase activity and bread loaf volume. The substitute ones performed better due to contribution of D-genome. The absence of this chromosome in complete triticales was found to be responsible for the lack of gluten in their flour. However, some complete forms showed an improvement in dough strength and bread making quality, which was thought to be due to translocation of D-genome (A and/or B). This improvement had eventually contributed to their use in areas where they performed better than substituted ones (Anonymous, 1985). Aniol (1985) compared more than 300 cultivars and lines of triticale in Poland and found
50% triticales more resistant to aluminium than wheat check (BH-1146), considered one of the most resistant wheat under Brazilian subtropical conditions. In Oregon, Kolding and Metzger (1985) identified several promising niches for triticale. At high altitude (1200–1300m) in intermountain region, winter survival of triticale ranged from 10-90% where as for two wheats “Luke” and “Nugaines” it was 40% and 10% respectively. Several winter triticale on sandy soils along the Columbia river, yielded as high as commercial wheats with higher disease resistance against yellow dwarf virus. However, at Willamette valley, triticale showed higher tolerance to disease, wet winter soils and Al toxicity. In the same year, Tuleen et al., published their five years studies on adaptative performance of triticale in Southern great plains (Oklahoma, Texas and New Mexico). In Oklahoma trials (1973-78), all triticales performed well, however, could not outyielded the wheat check “Scout 66”, while in high plains of Texas triticale showed comparatively better adaptation but were inferior in grain yield than wheat check in trials conducted during the years 1969-78. At Dallas (1974-78) triticale cv. TX–27034–26 and Beagle outyielded “Sturdy” and “Central” wheat checks. Zillinsky (1985) classified triticale as per their adaptive nature in different parts of the world. Spring triticale were adapted to rainfed, sandy loam found in temperate highlands and in plains e.g. Hungary or in Humantla (Iberian Peninsula) or may be grown in semitropical highlands of Eastern Africa, Ethiopia, Nepal, Michoacan, Mexico, Colombia and in Brazil; winter and facultative types were widely adapted. Winter triticale were grown in Eastern and Central Europe, Central and North USA. Facultative spring types were grown in western parts of Europe and in some parts of Southern USA. Forage triticales were also commercially produced in many area of the world like South Africa, Argentina, Mexico, Southern, Central and South Western USA.

Triticale research from its beginning to mid 80’s was tremendous. A crop with tall and late maturing plants, susceptible to most wheat diseases and
with poor grains was transformed into a crop with enormous potential for cultivation in environments that have not been traditionally favourable for wheat cultivation specially the poor and acidic soils, the tropical highlands and semi-arid regions. The temperate climates of many countries like Poland, Russia, France and Canada were identified where triticales were cultivated on large scale (Varughese et al., 1986). Tolerance to mineral stresses under certain conditions toxic to common wheat varieties, triticale appeared as an alternative for such conditions too. Breeding triticales for nutritional efficiency and tolerance to mineral toxicities should be considered, as the crop appears to have meaningful genetic variability and is agronomically, economically and ecologically feasible. Camargo et al. (1988) compared the response of wheat, triticale and rye to Fe$^{3+}$ concentrations between 0.056 and 40.0 mg l$^{-1}$, they observed reduction in the root length in all three crops with a combined tolerance to iron and aluminium toxicities in wheat and triticale and stressed that these resistant varieties should be considered as valuable source to breeders for tolerance. Besides showing tolerance to Al and Fe$^{3+}$, triticale also possess high tolerance for copper (Graham, 1978), manganese (Kaur and Takkar, 1987) and salinity (Francois et al., 1988).

Yield data from the 16th ITYN for different agroclimatic regions (acid soils, irrigated subtropical dry lands, highlands, Mediterranean and winter regions) showed that the top five triticales out yielded bread wheat checks in all environments except in irrigated subtropics. In winter with spring planting, both triticale and wheat were inferior to local check. Triticale “Beagle” and “Eronga” known for their wider adaptation were ranked high in nurseries (Varughese, 1988).

Data from the 18th ITYN (Abdalla et al., 1989) across 63 locations (African region, France, Germany, Poland, Spain, India, etc.) indicated the average grain yield of triticales ranged from 3784 to 5017 kg ha$^{-1}$. The complete triticales showed again their superiority as in previous ITYNs reports
over substitute ones, local checks and bread wheat check, and were ranked among the top five high yielding triticales. In dry lands, winter regions, high production winter region, Meditterranean region and subcontinental region, the triticales yielded higher and/or equal to the overall location means, indicating their higher adaptations in those regions. At Ludhiana, Punjab (India) with 30°56'N latitude, 75°52'E longitude and 747m elevation above sea level, data recorded from yield trials on 24 triticale cultivars showed superiority of many cultivars over local triticale check TL-1210. The average mean grain yield was recorded as 4465.7 kg ha⁻¹ with “JL090” at top, yielded 5589 kg ha⁻¹. The local check TL-1210 was ranked at 9th position.

Lapinski (1989) carried out studies on adaptation of triticale to Polish conditions. The correlation studies conducted between different parameters revealed that earliness was equally an important adaptative character as winter hardiness and lodging resistance. It was found that grain weight/volume exists as an index for adaptive ability. Later, Lapinski et al. (1996) attempted for tetraploid triticale, which remained curiosity in Poland for some time. After crossing the tetraploid triticale with hexaploid ones, followed by back crossing with tetraploid ones, newer tetraploid triticales were obtained. When tested, these triticales proved good in yield potential than previous primary triticales, better in acidic soils with Al toxicity and also higher in disease resistance. However, the one important problem of sterility remained as such.

Fox et al. (1990) examined the yield and adaptation of hexaploid spring triticale, using grain yield data from 8th to 14th International Triticale Yield Nurseries (ITYNs) and adaptational differences of complete and substituted triticale, a trend towards improving yield and adaptation may be observed. Grouping of genotypes as per their rank across the sites, showed a tendency for complete and substituted triticale to perform differently, suggesting that diversity for adaptation may be increased by utilizing both types in breeding programmes.
Besides showing higher adaptation in acidic and sandy soils of the temperate climates in traditional rye areas, triticale was further developed in humid and semi-arid tropical environments. In humid subtropics with acid soils, triticale's potential relies on its broader disease resistance, high yield potential, tolerance to toxicities (Al, Mn, Fe) and its efficiency in phosphorus uptake. In semi-arid regions with drought and salinity stress, adaptation is related tolerance to boron toxicity and efficiency in utilizing water, Cu, Mn and Zn (Baier, 1991). Latter on yield trials with 18 to 23 triticale genotypes and 2 wheat cultivars were performed to study their adaptation in Brazilian warmer regions. Results over five years (1989-93) from 7 locations confirmed the superior adaptation, yield potential and disease resistance of triticale at 400-1000 m altitude and 30° and 29° S latitude on acidic soils with Al toxicity. However, at lower altitudes, triticale remained behind wheat, which was due to high temperature during tillering. Low night temperature was preferred for triticale to express its yield potential (Baier, 1996).

Chromosomal confirmation and profound adaptation difference between substituted and complete types were important factors affecting yield potential and adaptation of triticale. ITYN results and new varietal release suggested an adaptive advantage of complete triticale that carries the 6D (6A) substitution because it reduces height, better adaptation to marginal soils, higher test weight and more wheat like architecture. These adaptive differences associated with substitutions suggested that the exploitation of other D(A), D(B) and D(R) substitution and/or translocations by triticale breeders may be useful strategy to increase its yield potential and adaptation (Lukaszewski, 1991).

Triticale as a novel cereal had increased its importance in the semi-arid cereal growing regions of the world. The newer released cultivars developed mainly by CIMMYT were devoid of many drawbacks of earlier cultivars (like shrivelled seeds and sterility). Mergoum et al. (1992) analysed the adaptive ability of triticale in the Middle East-North Africa (Morocco). Triticale
outyielded all other cereals in all environmental conditions except the most favourable environments. With the application of N and P fertilizers, yield was enhanced even sometimes up to double by modest inputs.

At Sao Paulo (Brazil), Felicio et al. (1993) evaluated 23 triticale cultivars and 2 wheat check for adaptation, yield and quality characteristics. The triticale “Nutria-400”, “Tarasca-87”, “Nutria-7272” and “IAC-1” showed higher regional adaptability. Resistance to leaf rust was also shown by some triticales. Triticale cultivars also proved superior to wheat check in baking and milling qualities with an 18% higher bread specific volume. Under Mediterranean condition, Josephides (1993) studied the adaptation of barley, triticale, durum wheat and bread wheat for five years under 23 different agroclimatic conditions. The regression analysis showed the susceptibility of barley to lodging and triticale dependence on late season precipitation. Durum wheat and triticale showed an average response to different yielding environments and were significantly different from bread wheat and barley. The cultivation of triticale at the expense of durum wheat was not feasible as both have same grain yield but higher than barley (5%) and bread wheat (7%).

Royo et al. (1993) studied seven complete and twelve substituted triticales to specific soil types with pH ranging from 5.2 to 8.2 in a series of twenty trials (1989-90) across Spain at 14 locations (37°28'N 2°09'W – 43°22'N 8°24'W) at different altitudes ranging from 26m to 800m above sea level. Soil pH was found single most important environmental factor to explain the adaptation of complete and substituted genotypes in majority of sites. Complete genotypes outyielded substituted ones in many sites particularly in soils with acidic pH. Triticale adaptation to acid and alkaline soils seemed to be largely controlled by the single wheat/rye chromosome 2D (2R) substitution, for which both types differ. Complete triticale in general were better adopted to acidic soils, whereas substituted types were more suited to alkaline soils with high fertility.
Results obtained from 21\textsuperscript{st} (1989-90) and 22\textsuperscript{nd} (1990-91) ITYNs clearly showed the wider adaptation of both the nurseries all over the world. Advanced triticale lines were distributed in 65 and 58 countries respectively by CIMMYT to observe their adaptation and yield potential. Complete triticales have shown higher adaptation and yield than the substituted ones (Pfeiffer \textit{et al.}, 1993).

As reported earlier, the potential of triticale to Fe\textsuperscript{+++}, Cu and Al toxicity, it showed tolerance to Cd too. Yang \textit{et al.} (1995) made a comparative study of cadmium tolerance in different crops (Triticale, Maize, Soybean, Cucumber). Triticale showed higher tolerance as compared to other crops. During the same year, Mekni and Yau (1995) published their six years (1978-83) preliminary assessment of yield potential and adaptation of triticale carried out in drier areas of West Asia and North Africa. The testing sites were grouped into four broad geographical regions of North Africa, Mediterranean West-Asia, Non-Mediterranean West Asia and the rest of the world. Grain yield of triticales over six seasons was constantly higher in the “rest of the world group”. Stability analysis showed that triticale was less responsive to improved condition, though similar to barley in low yield environments. However, locations characterized by long vegetative period, high rain fall and high incidence of diseases, favoured triticale.

Statistical analysis with grain yield data was used by Varughese \textit{et al.} (1996a, b) to identify the adaptation of spring and winter, complete and substituted triticales. The complete triticale showed adaptative advantages in areas with abiotic and biotic stresses. However, under high production conditions, complete and substituted triticales showed little difference but were inferior to wheat. This caused shift in spring triticale at CIMMYT of complete to substituted from 25:75 in 1985 to 95:5 in 1992. According to them, the acceptance of triticale as a crop by farmers was mainly due to (i) superior performance of triticale under biotic and abiotic stress conditions (ii) high biomass production and high regeneration capacity after grazing and (iii) as a
nutritive feed for monogastrics, poultry and ruminants. With this acceptance, the triticale production increased from one million hectares in 1992 to 2.5 million hectares. The most contributing countries were Europe (78%), North America (7%), Africa (6%) and Australia and New Zealand (4%). It is interesting to mention here, that for the first time, 500 hectares of land under triticale cultivation in India was also listed in the estimated world triticale production data. This may be considered as a positive sign, as the interest in Indian farmers may develop for the cultivation of triticale as a crop.

During the same year, some promising triticale cultivars were released and their adaptation and yield potential was evaluated in different environmental regions. Coutinho et al. (1996) registered three new cultivars (Crato, Arruda and Alter) for commercial cultivation in Portugal, which showed better adaptability, with improved test weight and grain yield potential. Gonzanlez-Iniguez and Pfeiffer (1996) introduced “Lamb-2” triticale cultivar for commercial production under low and moisture stress conditions in the central highlands of Mexico. When tested across 24 environmentally different locations, it outyielded the standard check by 35% and was found to show higher adaptation under drought conditions and increased moisture conditions. Under the Mediterranean regions of Europe, West Asia and North Africa, Yau-Sui and Miloud (1996) studied the performance of “Drira out-cross 7” as a check in durum wheat yield trials for six years (1987-92). It yielded highest, however, its performance in West Asia was not consistent with the poorest performance under irrigation conditions in Egypt.

Boggini et al. (1997) carried out trials with durum wheat, soft wheat, barley, oats and triticale at Sicily (Italy), where the cultivation of main winter crop (durum wheat) was found economically expensive. The data obtained from these trials showed that barley and soft wheat yielded higher than durum wheats. Triticale and oats, although showed better adaptation under Sicilian agroclimatic conditions but could not replace other crops due to lower yield.
During the same year, Bletsos et al. carried out series of six experiments at two different locations differing in soil and weather conditions, while working in Greece. They evaluated two cultivars each of triticale and barley for their hay and grain yield. Both the cultivars of triticale especially triticale cv. Niovi showed better adaptations (with mean temperature 0.2°C – 27.7°C and rainfall variation from 1 to 198.5mm). Ozkan et al. (1999) conducted stress tolerance study in hexaploid spring triticale under Mediterranean environment. During the trial, twenty genotypes were grown and evaluated for heat and drought tolerance under conditions of Adana (Turkey).

On acidic soils, Al toxicity acts as a main limiting factor for plant performance. Breeding of adapted genotypes presents an alternative to correlative lime application. Oettler et al. (2000) grew 20 triticale genotypes for 2 years on acidic, Al-toxic (pH 4.4) and lime amended soils with pH ranging from 5.0 to 6.3, in Brazil. Various traits assessed showed reduction with a higher reduction in grain yield (51%) due to acidic soils. Despite a substantial genotype × year interaction, the ranking of genotypes for acid soil tolerance did not change during the study. Genotypic variation was higher on acidic than on lime-amended soil. Higher adaptability of triticales to different biotic and abiotic stress conditions was confirmed by the new varietal release with considerable improvement in adaptation and yield potential due to broadening of genetic base, in the successive breeding programmes. In Canada, new cultivars were released by Salmon et al. (2000) and McLeod et al. (2001). (a) “Bobcat” showed higher adaptability in Canada particularly in the parkland area, with a good winter survival, resistance to stem and leaf rusts and to lodging. (b) The other cultivar “Ac Ultima” was also widely adapted in Canadian prairies. This new cultivar under field trials recorded high yields, excellent lodging resistance, early maturity and high 1,000 grain weight as compared to the check cultivars.
In Mexico, the new complete hexaploid triticales developed at CIMMYT showed a remarkable improvement in yield and adaptation, when compared to previously released cultivars. The “Moravilla-TCL-99”, “Cerillo-TCL-99” and “Supremo TCL-2000” registered by Campuzano et al. (2001), Mergoum et al. (2001) and Sierra et al. (2001) respectively, showed high adaptation under all megaenvironments (arid regions with high inputs under full and half irrigations, high rainfall regions and heat stress) in Obregon at 40m altitude and 27°5'N latitude and Toluca Mexico at 2640m altitude and 18°N latitude. All the three new cultivars were superior in grain yield, resistant to winter hardness, new race of yellow rust, leaf rust, septoria, stem rust and moderately susceptible to harvest time sprouting and fusarium head blight disease.


2.5 Yielding ability

Yield potential of any crop is defined as, “The ultimate yield attainable in any geographic region when all controllable production factors are optimum and uncontrollable factors, mainly weather conditions are generally favourable (Stanford and Legg, 1984). Most of the earlier reports regarding yield performance of triticale indicated that it was not competitive with wheat except
in certain areas and environments. Therefore, there were number of reports where lower yield of triticale as compared to wheat have been reported. Ingold et al. (1968) studied the yield performance of 33 varieties of octaploid triticale with wheat and rye in Switzerland. The average grain yield of triticales was found only 78.3% than that of wheat and 79.1% to that of rye. Briggle (1969) tested several cultivars in Mexico and found an improvement in their yield potential, however, these triticales could not compete successfully with wheat. He also reported the results of CIMMYT, in which triticales were grown together with wheat and barley, which competed well with barley varieties but were inferior to Mexican semi dwarf wheat check.

Yield of triticale with barley and oats at two places in North Dakota (USA) during 1967-69 was compared by Busch (1970). The average grain yield of all triticale cultivars was found to be 47.8% in 1967, 70.2% in 1968 and 70.7% in 1969 showing a progressive improvement compared to barley and oats at Williston. However, at Fargo, the results were disappointing as triticales yielded 46.4%, 58.2% and 69.5% in consecutive years from 1967-70. Barnett et al. (1971) also compared the yield of triticale with wheat in Florida (USA). The triticale yielded 17% lower than wheat due to lower number of ears plant$^{-1}$ (31%), although producing 20% more grains ear$^{-1}$ than wheat.

At CIMMYT, Zillinsky and Borlaug (1971a) reported the poor yield of triticale in earlier trials. However, an improvement was found later with the introduction of Armadillo strains, but the yields were still not higher than that of wheat check. Gustafson et al. (1972) conducted field trials at 5 sites in California (USA) to compare the yield of several triticale cultivars with wheat and rye. It outyielded rye in all trials but remained behind the wheat in grain yield.

The lower yield of triticale as compared to wheat was also reported by Barnett et al. (1973), Szigat and Muller (1973), Jones and Hooks (1976), Andrascik and Licko (1977), Bhardwaj and Agarwal (1978), Inam (1978),
Abbas (1980), Abbas et al. (1983), Alvi (1984) and Malik (1988). The lower yield of triticale was associated with problems related with its yield contributing characteristics like poor fertility, shrivelled grains, less ears, lower 1,000 grain weight and higher plant height, the last being also responsible for lodging. Plant breeders at CIMMYT and other places undertook these problems and very significant improvement has thus, been made by broadening the genetic base of this hybrid cereal which ultimately led to higher genetic yield potential. As a result of intensive crossing between wheat × rye, wheat × triticale and triticale x triticale, new advanced cultivars were released from time to time which were tested at various agroclimatic conditions around the world for their yield potential and adaptability.

Triticale, which was regarded as low, yielding crop, had started to compete well with best of wheats. In certain geographic regions, it was found at par with wheat while in some other regions it completely outyielded the wheat and other cereals (Inam, 1992). In east Flevoland (Netherlands) field trials on three cultivars each of four winter cereals (wheat, rye, triticale, barley) were conducted by Ellen (1993), to study their yield performance. The triticale cultivars on an average yielded (8200 kg ha⁻¹) higher than rye (6640 kg ha⁻¹) and barley (66220 kg ha⁻¹) but were found inferior to wheat (8740 kg ha⁻¹). However, triticale produced higher grains ear⁻¹ and grains m⁻² than other three cereals. Similar trials were also conducted by Mazurek (1994) on four winter cereals. Triticale yield was found matching to other cereals on very good rye complex soil, and it exceeded wheat and barley in weak rye complex soils.

It may be pointed out that besides the lower yield in earlier reports (60’s and 70’s), there were also reports of its matching or even higher yields during that period too. Mention may be made of Shebeski (1961) in Canada who reported higher yield of triticale than bread wheat, Sapra et al. (1971) on sandy soils of Kensas (USA), Chauhan and Bajpai (1972) at Kumaon hills, Pantnagar (India) on acidic soils. According to Hulse and Spurgeon (1974), the best
triticale cultivars outyielded the highest yielding wheat varieties in both summer and winter plantings in Mexico. Triticale yield was recorded as 83.5q ha\(^{-1}\) as compared to wheat 72.45q ha\(^{-1}\). This rapid increase in yield was due to the introduction of Armadillo strains. The two gene dwarf triticale strains appeared in 1972-73 during CIMMYT yield trials at Sonora. It was expected that these strains will equal or surpass in yield to the best wheats (Zillinsky, 1974). The yield gap between best wheat and triticale was further improved when triticale yielded 15% more than the wheat at CIMMYT (Wolff, 1976).

After surpassing wheat in the 5\(^{th}\) ITYN, the successive ITYN trials more or less, continuously registered higher yield in triticales. As may be observed from the results of 11\(^{th}\) ITYN (1979-80) across all locations, showed higher grain yield of triticale cv. Beaguelita ‘S’ and Ram ‘S’ (45 and 46q ha\(^{-1}\) respectively) as compared to wheat check “Pavon” (42 q ha\(^{-1}\)), Anonymous (1981). The higher yield potential of triticale was also reported among others by Martin and Maurer (1973), Jenkins (1974), Pavlov et al. (1976), Gustafson (1982), Moinuddin (1986), Dimitrov (1988), Reddy and Bahl (1989), Aziz (1991), Fatima (1993) and Tarannum (1998).

The comparison of yield in the nursery trials at Yaqui valley of Sonora extending for 10 years (1969-78) has shown an upward trend in the yielding ability. Thus, the average grain yield of top strains showed an improvement from 2358 kg ha\(^{-1}\) during 1\(^{st}\) trial (1968-69) to 8526 kg ha\(^{-1}\) in 10\(^{th}\) trial (1977-78). Similar type of improvement was also found in ITYN’s from 1969-70 to 1976-77 (Zillinsky, 1985). He further reported that the “Mapache” a single triticale cultivar included in the ISWYN (1977-78) among the 50 best wheats, yielded high (4212 kg ha\(^{-1}\)) than top wheat cultivar “Naczari” which produced 4020 kg ha\(^{-1}\).

The introduction of complete triticales in the international trials during late 70’s looked promising due to their higher yield potential than substituted
ones. Comparison of the data from 10\textsuperscript{th} to 16\textsuperscript{th} ITYN showed an improvement from 4163 kg ha\textsuperscript{-1} in 10\textsuperscript{th} ITYN to 4266 kg ha\textsuperscript{-1} in 16\textsuperscript{th} ITYN, with 4055 kg ha\textsuperscript{-1} and 5478 kg ha\textsuperscript{-1} in 16\textsuperscript{th} and 18\textsuperscript{th} ITSN's respectively. Whereas substituted triticales recorded 3919 kg ha\textsuperscript{-1} in 10\textsuperscript{th} and 3788 kg ha\textsuperscript{-1} in 16\textsuperscript{th} ITYN, with 3658 kg ha\textsuperscript{-1} and 5048 kg ha\textsuperscript{-1} in 16\textsuperscript{th} and 18\textsuperscript{th} ITSNs respectively (Varughese, 1988). It was further reported that the average grain yield of top five triticales in 16\textsuperscript{th} ITYN was found higher than the bread wheat check. A comparison between ITYN and ISWYN for past 16 years indicated that bread wheat tend to yield about 8\% below its potential when grown among triticales.

Yield data of the 18\textsuperscript{th} ITSN and ITYN (Abdalla \textit{et al.}, 1989) with 175 or more cultivars indicated that the average grain yield over all locations was higher which revealed its improvement in yield potential when compared to early reports. In Belgium, during 1984-88, Baets and Haesaert (1989) conducted field trials on four cereals (wheat, triticale, barley, rye). It was found that rye yielded 13.7\% more grains than wheat, barley 15.4\% more and triticale 32.2\% more than wheat. In the field trials in Brazil under irrigated conditions, Staut \textit{et al.} (1989) compared 17 cultivars of triticale with that of 3 wheat cultivars. The average grain yield of triticale exceeded to wheat. Sadiq (1990) at Faisalabad (Pakistan) compared the yield potential of advanced triticale cultivars with bread wheat, durum wheat and barley under irrigated conditions and reported that the triticale outyielded wheat and barley. During the same period in India, Moinuddin \textit{et al.} (1990) and Samiullah \textit{et al.} (1991) at Aligarh in continuation of the earlier work on this crop further studied the yield performance of triticale, wheat and rye (Russian rye). All the triticale cultivars outyielded rye and two cultivars of triticale outyielded the wheat check.

Higher yield of triticale than barley was also recorded by Ryan \textit{et al.} (1992) in Morocco, while at Narrabri in New South Wales, Sweeney \textit{et al.} (1992) reported that early and midseason types of triticale appeared to have reached yield parity with the adapted wheat cultivars and triticale at all sowings, yielded 19\% more than
wheat. The new varietal release during the same year for commercial purpose showed the high genetic yield potential of triticale. Bruckner et al. (1992) released “Sunland” with an average grain yield of 3303 lb acre\(^{-1}\), Hewstone and Jobet (1992) released “Antuco INIA” with an average grain yield of 7.5 t ha\(^{-1}\) while “Pika” by Salmon et al. (1992) with an average grain yield of 4.15 t ha\(^{-1}\) and “Meridal” by Weilenmann et al. (1992) with 7.9 t ha\(^{-1}\).

In CIMMYT spring triticales, significant increase in grain yield was recorded at Ciudad Obregon under irrigated and optimal conditions from 2.5 t ha\(^{-1}\) in 1968 to 9.7 t ha\(^{-1}\) in 1991. Comparison of complete triticales developed in 80’s and 90’s over three years in maximum yield trials revealed overall yield progress which resulted an increase in harvest index (16%), spike m\(^{-2}\) (12%), with an increase in grain m\(^{-2}\) (17%), increased test weight (12%). However, in comparison with wheat, triticales exceeded in number of grains spike\(^{-1}\) (40%), 1,000 grain weight (21%) but produced lower tillers reflected in spikes m\(^{-2}\) (− 40%) and number of grains m\(^{-2}\) (− 16%) (Varughese et al., 1996b). In Greece, Gogas et al. (1996) evaluated yield and quality characteristics of eleven triticale cultivars in comparison with widely cultivated wheat (Vergina) for a period of 16 years (1976–92) in 144 experiments under different environmental conditions. It was noted that triticales proved superior over wheat checks and the superiority was ranging from 0 to 10%.

Lauk et al. (1998) investigated four triticale cultivars “Modus”, Dato”, Presto” and “SV92280” in comparison with wheat “Sirvinta” and rye “Vambo”. Depending upon the share of yield components, grain yield at all dates was highest in triticale cv. “Modus” (7273 – 8101 kg ha\(^{-1}\)) than wheat (5279 – 6466 kg ha\(^{-1}\)) and rye (2524 – 4551 kg ha\(^{-1}\)). Lower grain yield of wheat was supposed to be associated with lower number of grains ears\(^{-1}\) while in rye, lower number of grains followed by lower 1,000 kernel weight.

More recently, Rao et al. (2000) conducted field experiments from 1993-96 on wheat, triticale and elytricum to study their yield and quality.
Triticale in seed yield surpassed wheat and elytricum in all experiments except in 1996, where triticale yielded comparatively lower as compared to wheat and elytricum. Similarly, number of complete hexaploid triticales were released which outyielded wheat as well as triticale checks. In Canada, two new hexaploid complete triticales “Bobcat” and “Ac ultima” were registered by Salmon et al. (2000) and McLeod et al. (2001) respectively. At 13 locations tested, Bobcat yielded 7049kg ha⁻¹ which exceeded winter triticale checks “Pika” by 110% and wheat check “Norstar” by 113%, while Ac ultima in 29 performance trials, yielded 5.3Mg ha⁻¹ and was found higher than triticale checks but equal to best wheat check “Pronghorn” (5.19Mg ha⁻¹), however, yielded 18% more than Canadian prairie spring wheat.

The new triticale cultivars developed at CIMMYT also registered higher yield than triticale checks and wheat, under different megaenvironments (ME1 – as high input environment with full irrigation, ME2 – high rainfall, ME4 – arid environment and ME5 – heat stressed environment). Thus, Campuzano et al. (2001) registered “Marvilla – TCL99” hexaploid triticale and released in Mexico during 1999. This cultivar with high yield potential when tested at Obregon during yield trials of 1993-97, yielded equal to triticale check under ME1 and ME3 while in ME5, it showed lower yield. In Mexico trials (1998-99), it yielded 20 and 22% higher than “Jilotepc” and “Haumantia” respectively in ME-5 while 12 and 17% higher in ME2 and ME3 respectively than two checks and also surpassed wheat in all other environments. Similarly, “Cerrillo-TCL99” hexaploid triticale registered by Mergoum et al. (2001) out yield triticale check in all environments at Obregon trials (1994-98). However, in ME-5, it yielded lower than check. In Mexico state, it produced higher yields in ME4 and ME2 during 1998-99 trials. The other cultivar “Supremo TLC-2000” registered by Sierra et al. (2001) also outperformed the checks at both Obregon and Mexico trials.
2.6 Mineral nutrition

Since the beginning of the plant domestication, attempts have been made to increase the yield potential of the crop plants. Initially gradual improvement in this regard was attained by using organic manures and leguminous crops. However, it was not until the later part of 19th century, when dramatic yield increase began to occur. It was based chiefly due to the increasing knowledge of the chemical elements required in plant nutrition and supplementation of soil with these nutrients in the form of chemical fertilizers. Credit goes to de Saussuse (1804) for his definitive discovery in this field supported by Liebig in 1840. It was the beginning of new era in plant nutrition.

Soil is a major source of essential nutrients and out of many nutrients found in plants, only 17 were listed as essential including Ni (Hopkins, 1999). More attention was paid, however, to N, P and K only as these were required comparatively in larger quantities and their regular application was found, therefore, necessary. Requirement for these three macro elements differ not only from one agroclimatic region to another but from crop to crop and even variety to variety.

Triticale, being not a popular commercial crop, received less attention regarding the fertilizer requirement in the beginning and also due to the problems associated with its poor yield, sterility, late maturity, plant height, lodging and grain shrivelling etc. Emphasis was given more to genetics and breeding studies mainly to overcome these problems. Due to this reason significant improvement was observed after the release of some new advanced cultivars with high genetic potential. However, this potential could be realised only when management factors were also kept at optimum. One of the most important among such factors involved was the application of fertilizers, which provided the source of required nutrients for exploitation of its optimum potential.
2.6.1 Nitrogen and phosphorus

Nitrogen is required by the plants for their growth, development and productivity. Its concentration in the plants varies between 1–3% of dry weight (Salisbury and Ross, 1994). Application of nitrogen to the soil in the form of fertilizers increases the ion exchange capacity of the plant roots, thus makes them more efficient in uptake of the other nutrients (Tamhane et al., 1970).

Due to the low availability, phosphorus appears as a limiting element in the natural ecosystem. 90% of the total phosphorus in the soil-plant-animal system, is present in soil, only 10% of it enters the plant-animal life cycle. The phosphorus present in soils occur in three forms, organic matter which accounts for 50%, insoluble phosphorus and small variable amount of soluble phosphorus that can be absorbed by the plant for completion of life cycle (Ozanne, 1980). Phosphorus being the second primary inorganic nutrient is also indispensable for all forms of life. It influences the vigour of plants and improves the quality of crops (Patnaik, 1987). It also increases the lateral roots, tiller and seed formation. Through its influences on the translocation of food to seeds, it affects the process of seedfilling and thus has a profound bearing on the economic yield of many crops including the cereals. In triticale, it has been reported to increase straw and grain yield (Moinuddin, 1986; Baier, 1991; Fatima, 1993; Shah, 1995; Gautam et al., 1996).

Not much work has been done on the phosphatic fertilization of triticale. Most of the workers reported about the application of uniform basal dose with varying nitrogen levels. The fertilizer trials conducted earlier showed that triticale did not respond to N-fertilization as effectively as to wheat due to greater susceptibility to lodging at higher fertilizer doses; Kiss (1968), Anonymous (1971), Zillinsky and Borlaug (1971b), Lafever and Schmidt (1972), Zillinsky and Lopez (1973), Mazurek and Mazurek (1974), Anonymous (1975). Thus, at Ludhiana (Punjab, India), field trial under 1st ITYN (1969-70) was conducted by Anand (1972) on ten cultivars of triticale by
applying a uniform dose of fertilizers at the rate of 29.5kg P ha\(^{-1}\) and 134kg N ha\(^{-1}\). Out of ten cultivars, four (Armadillo 147, 211, 1524 and Bronco 90) outyielded two wheat checks while rest remained inferior. Andrascik and Matusov (1973) at Nitra (formerly Czechoslovakia) recorded an optimum yield with 150kg P ha\(^{-1}\) along with 100 or 80kg N ha\(^{-1}\) in triticale and wheat.

Marked improvement in response to high N levels was achieved later. Results of 1975-76 nitrogen trials at CIANO (Mexico) indicated that average grain yield of ten triticales was higher or equal than best bread and two durum wheats at all N-levels varying from 0 to 300kg ha\(^{-1}\). Sulphur coated urea, a slow releasing N-fertilizer showed no advantage over conventional fertilizers regarding the triticale yield (Anonymous, 1976a).

Varietal differences regarding the fertilizer requirements have been observed by Afridi \textit{et al.} (1977) at Aligarh (India), which was later extensively studied by Inam (1978), Inam \textit{et al.} (1982a, b), Inam \textit{et al.} (1985), Inam \textit{et al.} (1992). He studied the effect of nine combinations of NPK on germination, leaf NPK content and yield components of three triticale cultivars Armadillo PPV-13, Armadillo T-15 and Badger PM-119 and wheat checks. It was found that fertilizer affected germination adversely in the field while nutrient contents increased significantly. \(N_{120}P_{60}K_{60}\) proved the optimum dose for most of the yield parameters. Similarly, response curves of the data on NPK trials were undertaken at CIMMYT (Mexico) on triticale, bread wheat and durum wheat using different combinations of fertilizers with nitrogen (0–300kg N ha\(^{-1}\)), phosphorus (0–90kg ha\(^{-1}\)) and potassium (0–30kg ha\(^{-1}\)). It was noted that semidwarf wheat gave the maximum yield at 225kg N ha\(^{-1}\) where as durums and triticale at 150kg N ha\(^{-1}\). At higher rates of N, durums and triticale were found susceptible to lodging (Anonymous, 1979a).

Such type of studies were also carried out by many workers who reported an increase in grain yield and other associated characters including quality with increasing doses of fertilizers involving N application along with
phosphorus Andraszik and Licko (1977), Misra (1977), Ali and Rajput (1978), Gajardo et al. (1978), Bishnoi and Mugwira (1980), Pino and Rodriguez (1980), Turbin et al. (1980), Ponce et al. (1981), Dimitrov et al. (1982), Ashfaq et al. (1984), Prasad and Singh (1983), Alvi (1984), Dimitrov (1985), Moinuddin et al. (1985), Ashfaq (1986), Moinuddin (1986), Tabl and Kiss (1986) and Samiullah et al. (1987). While Bolland et al. (1986) and Bolland (1992, 1994) carried out studies on effectiveness and requirement of phosphatic fertilizer on different crops including triticale in South Western Australia under different soil and climatic conditions. On the basis of requirement for constant higher yields, the effectiveness of rock phosphates was found to be about 1/5 of superphosphates for barley and 1/10 for triticale and trifolium. In other five trials, the phosphorus requirement for various crops (oats, triticale, barley, lupins) was determined in comparison to wheat for the maximum yield production of 70 and 90%. It was found that on acidic soils, triticale required only 50–70% while 100% in less acidic soils, when compared to wheat. Whereas the requirement for oats was found 50–70% less than the wheat. In glasshouse experiments, effect of water supply on phosphatic fertilizer was studied. The water stress was found to reduce the yield and maximum target by 20 to 40% and effectiveness of fertilizers by 20 to 60% due to reduction in yield potential. However, application of P fertilizers in subsoils with adequate water supply was found applicable in increasing the effectiveness of fertilizers and productivity of wheat and triticale.

Furlan et al. (1987) carried out field trials to study the effect of different phosphorus doses (30, 60, 120 or 180kg ha$^{-1}$) on triticale. Results obtained showed that the application of 120kg P$_2$O$_5$ ha$^{-1}$ proved optimum. Plant height was found to respond better to 120kg P$_2$O$_5$ ha$^{-1}$ while it declined above to this dose. Maximum grain yield of 5t ha$^{-1}$ was obtained at 120kg P$_2$O$_5$ ha$^{-1}$ as compared to 3.38, 3.58, 3.41 and 4.83t ha$^{-1}$ with 0, 30, 60 and 180kg P$_2$O$_5$ ha$^{-1}$ respectively.
Ben (1989) evaluated triticale cv. BRI along with many wheat lines, on acidic soils with Al toxicity, to study their phosphorus utilization efficiency under low (0kg) and high (80kg ha\(^{-1}\)) phosphorus application. It was found that under both conditions, triticale yielded higher along with other genotypes and showed better response to the higher P-application. During the same year, Lasztity (1989) studied the grain mineral composition of three cereals (wheat, rye, triticale) in field trials at Nyirlugos with acidic soils and Orbottyan with chalky soils during 1981 under different doses of phosphorus and potassium (0, 500 or 1000kg ha\(^{-1}\) each) in combination with 200kg N ha\(^{-1}\) at Orbottyan. On acidic soil, the Mn, Zn, Cu and Sr contents increased in all three cereals whereas on chalky soil, the Mn and Sr contents of rye and triticale increased but with decrease in Zn and Cu contents in response to PK application while Se contents were unaffected by it. However, the value of grain for human and animal consumption was not affected by PK application. At Aligarh, Moinuddin (1989) studied the effect of different nitrogen (150, 200 and 250kg ha\(^{-1}\)) and phosphorus (30, 40 and 50kg ha\(^{-1}\)) doses on four cultivars of triticale along with one check each of wheat and rye and it was found that leaf NPK were significantly increased by N+P regimes. Bali et al. (1991) while working on the production efficiency and economics of N-fertilization for two wheat and two triticale cultivars in Kashmir valley (India), applied different doses of nitrogen as 0, 40, 80 and 120kg ha\(^{-1}\). The average grain yield was recorded for two wheat cultivars and two triticale cultivars as 2.50–5.15t ha\(^{-1}\) in wheat cv. Sonalika, 2.10–5.14t ha\(^{-1}\) in wheat cv. WL-1562 whereas 2.47–5.93t ha\(^{-1}\) and 2.13–5.44t ha\(^{-1}\) in triticale cv. TL 1210 and DTS-963 respectively. With increasing N level upto 80kg ha\(^{-1}\), the grain yield also increased, beyond it no significant increase was found.

At Passo Fundo (Brazil), Rosa and Camargo (1991) conducted field trials on several wheats and one triticale at two levels of phosphorus (0 and 80 kg P\(_2\)O\(_5\) ha\(^{-1}\)). The grain yield increased with increasing phosphorus doses. The
grain yield of triticale in comparison to wheat was recorded higher under both control (2055kg ha\(^{-1}\)) as well as at 80kg P\(_2\)O\(_5\) ha\(^{-1}\) (2930kg ha\(^{-1}\)). Application of higher dose of phosphorus (80kg ha\(^{-1}\)) was compensated only by triticale due to higher yield.

Ryan et al. (1991, 1995) studied the performance of triticale and barley in Morocco under different weather conditions (normal and low rainfall and arid conditions) and nitrogen doses, which was applied as 0, 30, 60, 90, 120 or 150kg N ha\(^{-1}\). At all sites, 60kg N ha\(^{-1}\) proved optimum and application beyond it, did not significantly enhanced the grain yield. In other trials, under semi-arid zone, four cereals (barley, durum wheat, bread wheat, triticale) were evaluated under different phosphorus doses (0, 10, 20 or 40kg P\(_2\)O\(_5\) ha\(^{-1}\)) on phosphorus deficient soils. Biomass and grain yield increased with increasing rates of applied phosphorus, however, yield of durum wheat was recorded low due to disease damage.

In the Mugamba region of Burundi, Baragengana et al. (1992) conducted several trials during 1989-90 to study the effect of phosphorus and other nutrients (N, Cu, P, Mg) on triticale and wheat. Application of phosphorus increased grain yield from 43-58% in wheat and 19-26% in triticale. However, decline in yield was recorded at several sites, which was believed due to antagonistic effect of Cu uptake.

Naylor and Stephen (1993) performed some field experiments in Scotland between 1985-87, to examine the effect of different levels of nitrogen (0–180kg ha\(^{-1}\)) and plant growth regulator on mean grain weight and N-contents of triticale. Data obtained showed decrease in the mean grain weight with increasing grain yield due to N-fertilizer or chlormequate. A reduction in the N-contents was also observed with increasing grain size, however, nitrogen recovery (g m\(^{-1}\)) generally increased with increasing dose of nitrogen. Nitrogen fertilizer increased the grain yield with a reduction at excessive levels. Mean grain weight was increased upto 90kg N ha\(^{-1}\), above
which it showed decline. With increasing N-levels from 0–180kg ha\(^{-1}\), the amino acids responded differently. Decrease in proportion of alanine and glycine was observed with increase in histidine and phenyl alanine. Other amino acids showed a curvilinear response.

Stefanescu (1994) conducted field trials during 1983-1993 to study the effect of nitrogen and phosphorus on wheat and triticale at Turda (Romania). Winter wheat grown after soybean was given 0–120kg N ha\(^{-1}\) and after maize 0–160kg N ha\(^{-1}\) and after both proceeding crops 0–160kg P\(_2\)O\(_5\) ha\(^{-1}\). Wheat grain yields ranged from 3.30 and 2.08t ha\(^{-1}\) with no NP to 5.01t ha\(^{-1}\) with 90kg N after soybean and 5.04t ha\(^{-1}\) with 120kg N ha\(^{-1}\) after maize. In further trials with winter wheat and triticale, maximum grain yield was achieved with 120kg N + 80kg P\(_2\)O\(_5\) ha\(^{-1}\). Grain protein content of 5 wheats and triticales increased with increasing NP rates.

Jelic et al. (1995), while working on two triticales cv. “Zlatar” and “Sako” (Yugoslavia) during 1990-93, found the maximum response of both cultivars at 700 seed rate/square meter and at 120kg N ha\(^{-1}\). Fertilizers alone can not show the marked effect, unless supplied with other factors like irrigation. The effect of such combination was studied by Koszanski et al. (1995) on wheat and triticale on a good rye soil complex. Both sprinkling irrigation and nitrogen application (100–125kg ha\(^{-1}\)) were found productive and enhanced the grain yield by 40% and 104% in wheat while 15% and 131% in triticale respectively.

Twenty three hexaploid triticale x Triticum aestivum derivatives were grown in normal (60kg P\(_2\)O\(_5\) ha\(^{-1}\)) and phosphorus stress (0kg ha\(^{-1}\)) conditions to study the effect of phosphorus and response of the crop. Sixteen agro-morphological and physiological characters were recorded. Grain yield plant\(^{-1}\) followed tillers plant\(^{-1}\), spikes plant\(^{-1}\), early growth vigour and leaf area index were found most sensitive to P-stress conditions. It also delayed the heading and maturity of the crop. The overall characters associated and path
coefficient analysis revealed that relation for higher 1,000 grain weight and spikelets plant\(^{-1}\) in both conditions and for relatively taller plants under P deficiency could be useful for improvement in grain yield (Gautam et al., 1996 and Gautam and Sethi, 1996). During the same year Gil et al. (1996) and Jodko et al. (1996) reported that application of 150kg N ha\(^{-1}\), lignite coal and manure under previous crop, improved various quality characteristics of winter triticale cv. Bolero in Poland while Kisiel (1996) worked out 151.69kg N ha\(^{-1}\) as an optimum level on profit function basis and 143.62kg N ha\(^{-1}\) on the basis of functional analysis of cost per piece. Similarly, Oettler (1996) evaluated 36 triticales in breeding programme for carrying out study on N-use efficiency under N-stress and N-sufficient conditions.

In Poland, Koziara (1997) in field trials (1993-95) studied the effect of different nitrogen levels 0–150kg ha\(^{-1}\) on triticale cv. Coba under sprinkler irrigation. The highest grain yield (4.91t ha\(^{-1}\)) was recorded at 150kg N ha\(^{-1}\) under irrigated conditions, which also proved best for protein yield regardless of irrigation. Bruckner et al. (1998) carried out field trials under varied nitrogen treatments 30, 60, 90, 120 or 150lb N acre\(^{-1}\) (33.63, 67.26, 100.89, 134.52 or 168.15kg N ha\(^{-1}\)). Grain yield was found maximum with 90 and 120lb N acre\(^{-1}\) (100.89 and 134.52kg N ha\(^{-1}\)), depending upon the environment and cultivar. Yield components mainly tiller density and quality of amino acids increased linearly with nitrogen indicating potential for enhancing nutritive value. Despite N induced increase in amino acids particularly lysine content and relative nutritional value of triticale for feed, marginal return per acre was maximized at N levels and it was associated with maximum grain yield.

Pisulewska et al. (1998) studied the effect of three levels of nitrogen 0, 60 or 120 kg ha\(^{-1}\) on mineral contents P, K, Ca and Mg of four triticale cultivars and one wheat at prusy experimental station (Krakow Agr. University). The P and K contents were high in triticale than wheat. Nitrogen fertilization enhanced the K contents of the grain particularly at 120kg N ha\(^{-1}\). Szmigiel (1998) carried out field trials on three cereals (wheat, barley, triticale) grown in
N–S or E–S directions under low fertilization $N_{40}P_{40}K_{50}$ kg ha$^{-1}$ as well as high $N_{40}P_{80}K_{100}$ kg ha$^{-1}$ application. The higher doses proved beneficial in most of the yield and quality characteristics including grain number, spikes m$^{-2}$, protein content and leaf area index. The orientation of the rows played significant role in enhancing protein content particularly in N–S direction.

Klikocka (1999) studied the effect of different N rates (60, 90 or 120 kg ha$^{-1}$) and soil tillage on yield and structure of spring triticale. It was reported that the highest yield was given by 60 kg N ha$^{-1}$ while higher doses proved non-beneficial. During the same period, Mazurek and Jaskiewicz (1999) in pot experiment on 6 cultivars of winter triticale distinguished two groups, with two cultivars having high nitrogen dose utilization efficiency while other four cultivars with medium nitrogen utilization efficiency. In triticale nitrogen rate trials at Corvallis (Oregon), two triticale cultivars Alzo and Bogo were grown under three nitrogen doses 100, 150 or 200 lb acre$^{-1}$ (112.09, 168.15 or 224.19 kg ha$^{-1}$). It was found that both protein content and grain yield increased as N rate increased up to higher dose 200 lb acre$^{-1}$ (224.19 kg ha$^{-1}$). It was suggested that further increase in dose of nitrogen may increase both traits further (Anonymous, 2000).

2.6.2 Split nitrogen application

Fertilizers are mostly and traditionally applied in full recommended dose to the crop plants at the time of sowing. However, plants are unable to utilize entire amount of single application of fertilizers, as the large percentage of it does not remain available due to various reasons. This loss of costly fertilizers leads to the deficiency of inorganic nutrients in the soil, which ultimately results in low productivity. All the essential nutrient elements are required up to a certain level by each crop to achieve maximum productivity. Nitrogen, being the principal inorganic essential macronutrient, is required in higher quantity during the whole period of growth as compared to phosphorus and potassium. Among all three major nutrients, nitrogen fertilizers are highly soluble and are readily leached, volatilized (as ammonia), denitrified as $\text{NO}_3^{-}$ or immobilized in
organic forms, which are not easily available to the plants (Pratt, 1984 and Randall, 1984). Nearly 50% of the total nitrogen applied to the soil remained unutilised by the crop plants due to this wastage (Anonymous, 1971).

To safeguard against the loss of fertilizers (particularly nitrogen), different methods of its application have been suggested from time to time. One such method involves the basal application of nitrogenous fertilizers at the time of sowing and partly in split dose (top dressing) at different growth stages (mostly at tillering, preanthesis and/or even at postanthesis) although there were number of reports about the foliar application also. The beneficial role of such late N application in cereals has been reported by Hucklesby et al. (1971), Ellen and Spiertz (1980), Grant et al. (1985), Strong (1986), Flower and Brydon (1989), Janzen et al. (1990), Cassman et al. (1992), Peltonen (1993), Bulman and Smith (1994), Bulman et al. (1994), Sowers et al. (1994a, b), Abdin and Abrol (1997) and Destain et al. (1997). All of them reported an increase in grain yield and protein content either at individual level or together by split N application. However, late N application in split doses in dry areas was found less effective as compared to irrigated areas (Doyle and Shapland, 1991).

As far as triticale was concerned, most of the workers have applied nitrogen in full dose at the time of sowing by broadcast method to establish its nutritional status, although attention was also given to split N-application. Mention may be made of some earlier reports regarding the split application of fertilizers in triticale includes Anonymous (1976), Ali and Rajput (1978), Dhiman (1978), Bishnoi and Igbokwe (1979) Gajardo et al. (1981) and Singh et al. (1982).

Ashfaq (1986) at Aligarh conducted fertilizer trials on two triticales. In her first trial during 1981-82, nitrogen was applied either fully at sowing (100, 150 or 200kg N ha\(^{-1}\)) or in two instalments, partly at sowing and partly as top dressing at 70 DAS (B\(_{N100T_N50}\), B\(_{N100T_{N100}}\), B\(_{N150T_{N50}}\)). The phosphorus was applied as 13kg ha\(^{-1}\) and 26kg ha\(^{-1}\) at the time of sowing. All growth and yield
characteristics were significantly affected by split N applications with higher phosphorus dose when compared to single N application. Maximum effect was given by BN_{150}P_{26}T_{N50} (200kg N ha\(^{-1}\) + 26kg P\(_2\)O\(_5\) ha\(^{-1}\)). In the following year the efficiency as well as economy of the supplemental foliar spray of nitrogen vis-à-vis top dressing was evaluated in split plot design field trial. Nitrogen (20kg N ha\(^{-1}\)) was sprayed in one or two equal instalments at various growth stages (70, 90 and/or 120DAS), in such a way that spray treatment received a total of 120kg N ha\(^{-1}\) where as control received 150kg N ha\(^{-1}\). Spray treatments proved beneficial for increasing the ear weight, ear length and grain yield. However, the ear number, spikelets, grain number and 1,000 grain weight were recorded maximum in top-dressing treatment at 70 DAS. Fatima (1993) from the same location, conducted factorial randomized field experiments on four cultivars of triticale (Delfin, Drier, TL419 and Tigre’s) and wheat (HD2204) to study the effect of nitrogen and phosphorus. Nitrogen was applied as 100kg ha\(^{-1}\) before sowing and 50kg N ha\(^{-1}\) after sowing as top-dressing at tillering stage with two levels of phosphorus (45 and 60kg ha\(^{-1}\)) at the time of sowing. Split application gave the maximum values for most of the growth, yield and quality parameters. In another experiment on baking, improvement in the quality of triticale flour was observed and acceptable for bread making when mixed with wheat flour in 50:50 ratio.

Later, Honermeier et al. (1989) studied the effect of nitrogen (early and late) application on ear formation of winter triticale cv. Grado. Spike samples were taken from N-fertilized trials and observed a linear relationship between spike length, number of grains spike\(^{-1}\), number of florets spike\(^{-1}\) and spikelets to the size of first N-application. With excessive early N-application, the full storage of potential of ears (1,000 grain weight) was often not reached due to lodging, fungal infection and compensation between yield components.

Petr and Hradecka (1993) tested four cultivars of triticale cv. Dagro, Largo, Lasko and Korm in comparison to wheat (Regina) and rye (Breno) at
Czech Republic under different N-doses. Nitrogen was given 90 or 120kg ha\(^{-1}\) in split application along with growth regulators chlormequate, paclobutrazol or both at 3 litres ha\(^{-1}\) in autumn or spring. N-application particularly with 3 split applications each of 30kg ha\(^{-1}\), increased dry matter production m\(^{-2}\) and grain production (3.5–5.7t ha\(^{-1}\)) in 1987-89. High leaf area duration (LAD) values from heading to grain ripeness was found important for high grain yields. Late N-application alongwith application of growth regulators was found useful for the achievement of high leaf area duration.

Application of nitrogen in split doses on four cereals (wheat, rye, barley and triticale) was also studied by Ellen (1993) and Fossati \textit{et al.} (1993) on various triticale lines. They reported an increase in yield as well as in protein content and nitrogen related characters. Korona \textit{et al.} (1994) under field trials at Popielno (Poland) during the years 1987-89, studied the effectiveness of N-fertilization on spring triticale cv. Jago. Nitrogen fertilizer as urea was given as zero or combination of 30 or 60kg ha\(^{-1}\) before sowing, 30kg at stem elongation and 20kg ha\(^{-1}\) as urea (through foliage) or 30kg ha\(^{-1}\) as ammonium nitrate (through soil) at heading. Grain yield was recorded upto 5.36t ha\(^{-1}\) without N, 5.85t ha\(^{-1}\) with 30kg N before sowing, 6.36–6.41t ha\(^{-1}\) with 60kg N in 1 or 2 application, 6.72–6.96t ha\(^{-1}\) with 3N applications and 7.0t ha\(^{-1}\) with 60 + 30kg N ha\(^{-1}\). Application of nitrogen just after heading did not increase yield. N use efficiency was highest with 60 + 30kg N ha\(^{-1}\). Applying more than 90kg N ha\(^{-1}\) was found agronomically and energetically ineffective. During the same year, Wrobel and Budzynski conducted field trials on two cultivars of triticale to study the effect of nitrogen (0–120kg N ha\(^{-1}\)) while applying in split doses. It was given 0 or 60kg N ha\(^{-1}\) before sowing and 0, 30 or 60kg N ha\(^{-1}\) at feekes stages. Grain yield of cv. “Jago” increased from 5.15t ha\(^{-1}\) with no applied nitrogen to 6.45t ha\(^{-1}\) with 60kg N before sowing and 60kg N ha\(^{-1}\) after sowing. Whereas in cv. “Maja”, it ranged from 5.7t ha\(^{-1}\) with no nitrogen to 6.52t ha\(^{-1}\) with 120kg N in 3 splits applications. Grain protein content and yield were
highest with $60 + 0 + 60\, \text{kg N ha}^{-1}$. Lysine and isoleucine content and essential amino acids index decreased with increasing N rates but decrease was significant only at higher rates. However, lodging increased with increasing N-doses and was severe with $60 + 60 + 0$ or $60 + 30 + 30\, \text{kg N ha}^{-1}$.

The pot trial experiment with split N-application on triticale cv. “Maja” kept at 25, 50 and 70\% of maximum water capacity was studied by Koc (1996). Nitrogen was given 0–2g N pot$^{-1}$ (6kg soil) in split application before sowing and at tillering. The grain and straw yield increased only slightly in the absence of nitrogen fertilizer, with increasing soil moisture in the range of 5.1–5.8 and 7.6–9.1g pot$^{-1}$ respectively. With N, grain yield increased from 5.9–7.8, 19.0–23.0 and 20.9–29.6g pot$^{-1}$ at 3 moisture levels. The higher grain yield was associated with increase in spike length and number of grains spike$^{-1}$. However, N-use efficiency decreased with increasing N-rates. Wrobel (1997) conducted field trials on triticale cv. “Maja” in Poland to study the yield and quality characteristics under different N–levels. Nitrogen fertilizer was applied as 0, 60, 90 or 120 kg ha$^{-1}$ as ammonium nitrate with 60kg ha$^{-1}$ at the time of sowing and rest at Zadok’s stage (33 and/or 55) or 30 + 20 + 20 + 20kg ha$^{-1}$ as urea at stages 23, 33, 50 or 75 respectively. Nitrogen rate did not significantly affect yield components, however, 1,000 grain weight increased and it was highest when part of nitrogen was applied at stage 50. Grain yield increased from 5.15t ha$^{-1}$ to 6.32t ha$^{-1}$ with 60kg N ha$^{-1}$. Higher rates gave no further increase. The grain yield and protein increased upto 120kg N ha$^{-1}$ and the essential amino acid index was highest at 90kg N ha$^{-1}$. Kozdoj et al. (1997) in trials spread over four years, studied the effect of nitrogen fertilization on winter triticale cv. Presto. It was applied to the field as 90 or 150 kg ha$^{-1}$ in a single application on in split application with 60\% before sowing and 40\% at stage 30 or 39. Average grain yields were recorded as 5.71 and 6.37t ha$^{-1}$ at low and high N-rates respectively. Delayed N-application reduced average grain yield from 6.35 to 5.73t ha$^{-1}$ due to reduction in spikes m$^{-2}$ and grains spike$^{-1}$. 
Juchniewicz et al. (1998) carried out field trials in Poland during 1993-95 on spring triticale cv. “Maja”. Nitrogen was given 0, 20, 40 or 60kg ha\(^{-1}\) before sowing and 0, 20, 40 or 40 + 20kg ha\(^{-1}\) after sowing along with basal application of P, K, Mg (30 + 45 + 15kg ha\(^{-1}\)) or 60 + 90 + 30kg ha\(^{-1}\) respectively. Results obtained indicated that with increasing N doses grain yield increased and reduced production costs per ton. The highest profitability was obtain at 100kg N ha\(^{-1}\) whereas, 120kg N ha\(^{-1}\) slightly reduced the profitability coefficient. In other trial at the same location and with the same cultivar, Kisiel et al. (1998) applied nitrogen in split treatments as 30, 60 or 90kg ha\(^{-1}\) before sowing and 0, 30 or 60kg ha\(^{-1}\) after sowing. The highest profitability was obtained with sowing at 300 seeds m\(^{-2}\) and at 120kg ha\(^{-1}\) in which 60kg ha\(^{-1}\) was applied at stem elongation.

Ewert and Honermeier (1999) studied the spike initiation in response to two levels of nitrogen fertilizer (0 and 200kg ha\(^{-1}\)). The 200kg N ha\(^{-1}\) was applied in split doses (5 x 40kg ha\(^{-1}\)) on winter triticale cv. Grado and winter wheat cv. Taras at Rostock (Germany) over four years. It was found that number of spikelets of both main stem and tillers significantly increased with N-application at spikelet initiation and anthesis in wheat but did not affect triticale at spikelet initiation, however, the spikelet increased (2.4 spikelets ear\(^{-1}\)) at anthesis which might have occurred due to continuous initiation of spikelets in high N treatments and abortion in N stress conditions. Main stem initiated more spikelets than tillers but did not respond to different N application. The marked ability of N fertilizer was observed in triticale whereas wheat varied less. It was concluded that spikelets initiation in triticale was better adapted to lower N condition than wheat.

From the outgoing review it may be pointed out that there is always a scope for the improvement of any crop if subjected to intense study, as may be observed in case of triticale, going through the adaptation process under varied and adverse agroclimatic conditions and proving its potential in yield and quality as well.