Sri Lankan Journal of Technology SLJoT
2020, 01(1), 7-13

Research

Nitrogen Fertiliser on Plant Nitrogen Uptake and Partitioning in Different Wheat Species

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Received:2020-08-01 ∗ Accepted:2020-11-30 ∗ Published Online:2020-12-31

***Abstract*—**Nitrogen (N) partitioning in different wheat species under three N levels was studied by conducting two field experiments in 2012-2013 and 2013-2014 seasons at University of Nottingham farm, Sutton Bonington, UK. Ten geno types belonging to four wheat species including three ancient hull wheat species of cultivated Einkorn *(Triticum monococcum* L.), cultivated Emmer *(T. dicoccum)* and Spelt *(T. spelta* L.), and modern bread wheat *(T. aestivum)* were compared under three N levels (0, 100 and 200 kgN ha^{-1} in 2013 and 0, 100 and 150 kgN ha^{-1} in 2014). The interaction effect of genotype by fertiliser level was significant for straw, chaff and grain N% in both experiments ($P < 0.001$). N% of all plant organs were increased significantly when increased N supply ($P < 0.001$). The total plant N uptake (excluding root N) was greater in emmer under high N fertiliser level while spelt had the highest total plant N uptake at low and zero N fertiliser applications in both experiments. The total plant N uptake was significantly different between N levels ($P < 0.001$ in 2013 and $P < 0.001$ in 2014) and genotype ($P < 0.001$ in 2013 and $P < 0.05$ in 2014). The highest amount of N in straw and chaff was recorded in spelt genotypes.The amount of N in grains was high in emmer in 2013 though bread wheat recorded the highest chaff and grain N content in 2014 under the high level of N fertiliser. According to the results, it can be concluded that ancient wheat species of emmer and spelt could uptake more N than modern bread wheat and accelerated by N supply. Furthermore, the greater total plant N uptake of ancient wheat species may be associated with the height of the plant, since all ancient wheat species are significantly taller than modern bread wheat. Therefore, more N was partitioned to structural materials development of the stem hence stored more N in the straw at maturity.

***Keywords*—**Chaff, nitrogen partitioning, nitrogen uptake, straw, wheat species

I. INTRODUCTION

Nitrogen fertiliser is one of the key components of cost of production of wheat and may also contribute significantly to environmental pollution through nitrate leaching and nitrous oxide gas emission due to soil microbial denitrification (Neha, et al., 2020; Sylvester-Bradley and Kindred, 2009). At present, 170 million tonnes of ammonia, the main ingredient of N fertiliser, are produced globally per year or 465 thousand metric tons per day (Soloveichik, 2019). Fossil fuel consumption for producing ammonia by pressurising air using the "Haber-Bosch" process is very high. Since 1962 annual global N fertiliser consumption in agriculture has increased from 13.2 million tonnes to 106.7 million tonnes in 2017 (IFA Database, 2020).

The N uptake efficiency of winter wheat is about 50-60% (Barraclough, et al., 2010). Absorbed N by plants mainly used to produce photosynthetic tissues and structural tissues. Therefore, two major N pools could be theoretically identified as 'Photosynthetic N' and Structural N', while rest of the small proportion of N may be considered as 'Reserve N' (Lemaire and Gastal, 1997). At anthesis, 20-25% of above-ground N is accumulated in the true stem (Critchley, 2001) which exceeded the requirement for structural functioning of the stem. However, this high N% may be due to reserve N in the stem. The first N source relocated during the post-anthesis grain filling phase was the reserve N followed by photosynthetic N pool (Sarandon and Dalling, 1990). Pons and Percy (1994) suggested that structural N remains in the straw at harvest without redistributed to the grains. On the other hand, as a result of early and fast remobilisation of photosynthetic N during grain filling phase, grain dry matter content may be reduced due to rapid canopy senescence (Martre et al., 2003). Nutrients such as N available in the vegetative parts of the plant are remobilised to the developing grains during senescence (Lim et al., 2007). In wheat, leaf senescence has a strong relationship with remobilisation of N from leaf to grain resulting in 40-90% of grain N from the leaf. Further, it is estimated that over 70% of the remobilised N was stored during the pre-anthesis period in wheat (Kichey et al., 2007). Canadian red spring wheat contributed about 18% of flag leaf N for grain development (Wang et al., 2008) while winter wheat contributed about 75% of N remobilisation from the leaf (Pask et al., 2012).

Development of new varieties of bread wheat with high nitrogen uptake efficiency through traditional plant breeding and modern biotechnology is an alternative approach to reduce N losses to the environment (Hawkesford, 2014; Zörb, et al. 2014). Exploration of favourable traits associated with nitrogen uptake of the ancient wheat species would help to strengthen the genetic material availability of bread wheat breeding programs (Trethowan and Mujeeb-Kazi, 2008; Sparks, 2010). Therefore, the present study aimed to compare plant N uptake and relative distribution of total plant N among different plant organs in wheat species of Einkorn, Emmer, Spelt and modern bread wheat under varying N fertiliser levels.

II. METHODOLOGY

A. *Experimental site and treatments*

Two field experiments were conducted at the University of Nottingham Farm, Sutton Bonington, UK, in 2012-2013 (hereafter 2013) and 2013-2014 (hereafter 2014) growth seasons (Table I) under three N regimes. The genetic materials used in the experiments were cultivated Einkorn (*Triticum monococcum* L., a diploid with AA genome), cultivated Emmer (*T. dicoccum* L., a tetraploid with AABB genome), Spelt (*T. spelta* L., a hexaploid with AABBDD genome) and modern bread wheat (*T. aestivum* L., a hexaploid with AABBDD genome) (Figure 1A 1B). Ten genotypes were used in the experiments; three Einkorn landraces (1, 2 and 3), two Emmer landraces (1 and 2), three old cultivars of winter Spelt (SB, Oberkulmer and Tauro) and two cultivars of modern bread wheat (Xi 19 and JB Diego). Due to poor establishment and growth performances of Emmer 1 and Einkorn 3, data were not used in 2013 experiment for analysis and all Einkorn genotypes were excluded from the 2014 experiment. Seeds were obtained from a previous field experiment at Sutton Bonington. Though, originally, seeds for Einkorn, Emmer and Spelt genotypes were collected from the Archaeological Department at the University of Nottingham in 2007. Modern bread wheat cultivars were chosen from the Home Grown Cereals Authority (HGCA) recommended list released in 2008/2009.

Split plot design was used in both experiments where N treatment was randomised on the main plot and genotypes on the sub-plot with three replicates. Three N levels of 0 kgN ha^{-1}(zero N; NN), 100 kgN ha^{-1}(low N; LN) and 200 kgN ha^{-1}(high N; HN) were used in 2013. NH_4NO_3 was applied as N fertiliser at 40 and 60 kgN ha^{-1} at early tillering and stem elongation for LN treatment while 40, 80 and 80 kgN ha^{-1} was applied at early tillering, stem elongation and flag leaf emergence for HN treatment. Plant growth regulators (PGR) were applied three times from stem elongation to flag leaf emergence at 1.4, 0.2 and 0.5 l ha^{-1}.

In 2014, three N regimes equal to zero N (no fertiliser N applied; NN), 100 kg N ha^{-1} (Low N; LN) and 150 kgN ha^{-1} (High N; HN) were used. NH_4NO_3 was applied in two splits at 40 and 60 kg N ha^{-1} at early tillering and stem elongation for LN treatment while 40, 80 and 30 kg N ha^{-1}was applied at early tillering, stem elongation and flag leaf emergence for HN treatment. All plots were treated twice with PGR at 1 l ha^{-1} during stem elongation to flag leaf emergence. Based on the results of soil mineral N analysis in February of the respective year and N fertiliser recommendation for winter wheat in the UK, the amount of N fertiliser was calculated. The length and width of the individual plot was 12m x 1.625 m and each experiment consisted of 90 plots in total. The spacing between the two rows was 0.125 m (Figure 1C). All other crop management followed the best agricultural practices for UK wheat production.

TABLE I
DETAILS OF THE FIELD EXPERIMENTS CONDUCTED IN 2013 AND 2014 GROWTH SEASONS

Information	**2013 Experiment**	**2014 Experiment**
Previous crop	Winter oat	Spring oilseed rape
Sowing date	17th October 2012	19th November 2013
Soil pH	7.4	6.8
30 cm depth of soil		
Available Nitrogen	45 kgN ha^{-1}	75 kgN ha^{-1}
Phosphorus	67.5 mg l^{-1}	72 mg l^{-1}
Potassium	414 mg l^{-1}	216 mg l^{-1}
Magnesium	213 mg l^{-1}	221 mg l^{-1}

B. *Quadrat sampling at maturity*

The sampling was done at maturity when all plants were fully senesced using a quadrat (Figure 1D). A quadrat of 0.72 m^2 (1.2 m x 0.6 m) was used in 2013 experiments due to the uneven establishment of the genotypes while 0.25 m^2 (0.5 m x 0.5 m) was used in 2014 experiment. Pre-labelled paper sacks were used to collect uprooted plants at maturity in the field to avoid grain losses during transportation. Total fresh weight of the quadrat sample was measured without roots. Then the half of the sample was partitioned into leaf lamina, true stem (with leaf sheath) and ears. All segregated plant parts were oven-dried at 80°C for 48 hours to receive constant dry weight. The dried ears were hand threshed carefully and separated grains from the chaff (all parts of the ear except grains). The grains were re-dried to achieve a dry weight of the grain sample. The difference between the dry weight of the ears and grains were taken as chaff dry weight. Based on the dry weight of different plant parts, total biomass production of the quadrat sample was calculated.

Plant height was measured at maturity in the laboratory. Ten plants were randomly selected from the quadrat sample to measure plant height where main shoots were measured from the base to the tip of the spike, excluding awns.

C. *N analysis*

Dumas method was used to analyse N% of the finely ground planting materials using a Fisons NA-2000 elemental analyser

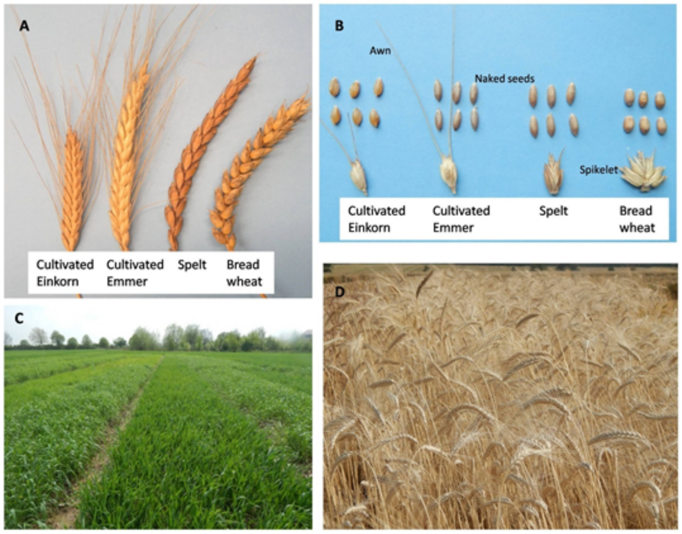

Fig. 1. (A) Morphology of the spike/ear of four wheat species; cultivated Einkorn (*Triticum monococcum* L., a diploid wheat), cultivated Emmer (*T. dicoccum* L., a tetraploid wheat), Spelt (*T. spelta* L., a hexaploid wheat) and modern bread wheat (*T. aestivum* L., a hexaploid wheat) (B) morphological variation of spikelets of four wheat species (C) Field establishment and early plant growth in 2014 experiment (D) Cultivated Emmer at maturity in 2014 experiment

(Fisons, Ipswich, UK) calibrated against Methyl-N standard (N content = 9.28%). N content in straw, grain and chaff was analysed at maturity and presented as a percentage. Total plant N uptake (N_{off}) was calculated at maturity (dry matter content of different plant organs multiplied by N% of the respective organ and presented as kgN ha^{-1}). Root biomass production and root N uptake were not considered in the present study.

D. *Statistical analysis*

Analysis of variance relevant to split-plot design was performed to test the phenotypic differences and N fertiliser effect on measured parameters. Data were analysed using GenStat 15th edition. Box-plot diagrams were used to illustrate the distribution of means of the parameters among the replicates.

III. RESULTS AND DISCUSSION

A. *Meteorological data of the experimental site*

The meteorological data for Sutton Bonington, UK (52^0 50' N, 1^o 15' W) were presented as temperature, rainfall and solar radiation for two field experiment, together with the long-term means (LTM).

B. *Temperature*

In 2013, the average annual temperature of the site from sowing (October 2012) to harvest (August 2013) was 9.3^{o}C which was 3.9% lower than the LTM of 9.7^{o}C, may be associated with low temperatures from January to April. In 2014, monthly temperature from sowing (November 2013) to harvesting (August 2014) was higher than LTM leading to an annual temperature of 11.65% greater than the LTM (Figure 2A).

C. *Rainfall*

LTM for annual rainfall in the experimental sites was 604 mm. In 2013, annual average rainfall was 483 mm, which was 121 mm (17%) less than the LTM. Therefore, overall, this season was dry for rain-fed crops including winter wheat. In 2014, January rainfall was more than double the LTM while in May it was 81% greater than the LTM. However, the total seasonal rainfall of 2014 was less than the long term total (Figure 2B).

D. *Solar radiation*

The total incident solar radiation from sowing to harvest for 2013 and 2014 was 3050 and 2836 MJ m-2, respectively. However, solar radiation from anthesis to the end of grain filling (June to August) in 2014 was greater than in 2013. It was 9 and 14% higher than the LTM in 2013 and 2014, respectively (Figure 2C). When compared to the 2014 season, 2013 seasons had more solar radiation and brighter conditions from anthesis to the end of grain filling.

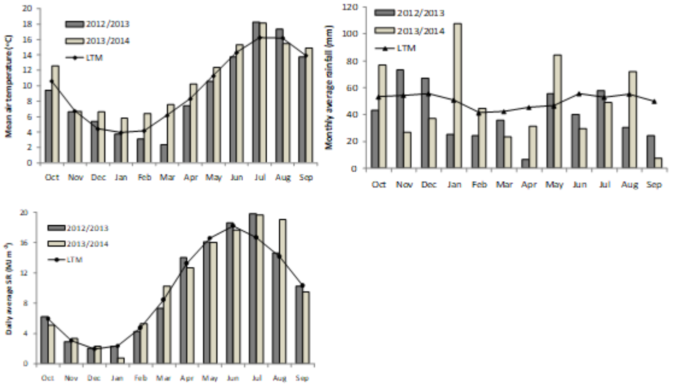

Fig. 2. (A) Monthly air temperature (^{o}C), (B) monthly average rainfall (mm) and (C) daily average solar radiation (MJ m^{-2}) in 2013 and 2014 growth seasons at Sutton Bonington. Long term mean (LTM) of mean temperature (1959-2011), rainfall (1961-2011) and Daily solar radiation (2000-2011) are shown as a line graph (Source: www.metoffice.gov.uk)

E. *Plant height*

Effect of N fertiliser on plant height was significant in 2013 ($P < 0.01$) and 2014 ($P < 0.05$) experiments. It was observed that there was a positive effect on plant height with the amount of N fertiliser applied to the plots in both experiments. Similar results were reported by Longin et al. (2016), based on the comparative study of hulled wheat species of Einkorn, Emmer, and Spelt together with naked wheat species of durum and bread wheat. The genotypic effect was significant ($P < 0.01$) and GT x N was not significant in both experiments for the plant height (Table II). According to results, it is obvious that ancient wheat genotypes are taller than bread wheat genotypes, despite the effect of N fertiliser. On average, Einkorn, Emmer and Spelt were 37 cm, 45 cm and 35 cm taller than bread wheat, respectively, in 2013 experiment while Emmer was 52 cm taller than bread wheat in 2014. Longin et al. (2016) also found that Einkorn, Emmer and Spelt plants were 30 cm taller than durum and bread wheat.

TABLE II
PLANT HEIGHT AT MATURITY IN 2013 AND 2014 EXPERIMENTS

GT	**Plant height(cm)**					
	2013			**2014**		
	NN	LN	HN	NN	LN	HN
JB Diego	63.97	78.60	77.52	62.33	75.52	76.73
Xi 19	59.97	79.59	76.77	65.17	75.67	76.27
Spelt Tau	96.07	113.02	111.87	105.17	116.27	116.17
Spelt SB	101.11	107.07	115.56	113.17	122.83	132.67
Spelt Ober	91.37	110.07	120.44	101.00	115.17	126.17
Emmer 1	-	-	-	121.51	127.55	132.52
Emmer 2	108.13	125.71	120.44	105.67	128.52	129.54
Einkorn 1	95.59	112.19	103.37	-	-	-
Einkorn 2	109.31	116.88	118.86	-	-	-
SED; GT (df)	2.902 (7)***			2.514 (6)***		
N (df)	2.702 (2)**			3.645 (2)*		
GT x N (df)	5.422(23)^{NS}			5.435 (20)^{NS}		

NN = zero fertilizer applied LN = 100 kgN ha^{-1}
HN = 200 kgN ha^{-1}
***significant at $P < 0.001$ **significant at $P < 0.01$
*significant at $P < 0.05$ NS = not significant

F. Above-ground biomass partitioning at maturity

The proportion of above-ground biomass (AGB) partitioned to leaf lamina was significantly affected only by genotype ($P < 0.001$) in 2013. However in 2014, genotype ($P < 0.001$) and GT x N ($P < 0.01$) were significant. AGB partitioning into leaf lamina was not significantly affected by N levels in both experiments. Allocation of assimilates for true stem and ear was significantly different among genotypes ($P < 0.001$), N levels ($P < 0.05$) and GT x N ($P < 0.01$) in 2013 while it was only significant for genotypes ($P < 0.001$) in 2014 (Data not shown). In general, all genotypes allocated more assimilates toward ear followed by true stem and then leaf lamina regardless of N level in both years. In general, above-ground dry matter production per plant increases with plant height (McCaig and Morgan, 1993).

G. Straw, chaff and grain N content

Straw (include true stem, leaf lamina and leaf sheath) N% and grain N% were significantly affected by genotype ($P < 0.001$), N treatment ($P < 0.001$) and GT x N ($P < 0.001$) interaction for both experiments. Similarly, chaff N% was also significantly influenced by genotype ($P < 0.001$), N treatment ($P < 0.01$ in 2013 and $P < 0.001$ in 2014 and) and GT x N ($P < 0.001$). N% increased in all plant parts with N fertiliser supply (Figure 3A, 3B and 3C) (Table III and IV). In 2013, the lowest grain N% was recorded in bread wheat cultivar JB Diego for all N levels while the highest value was recorded in Emmer 2, Einkorn 1 and 2 at HN. Straw N% was significantly higher ($P < 0.001$) in ancient wheat species than bread wheat under LN and HN but Einkorn 2 recorded low straws N% at NN. In 2014, Emmer 2 had the highest grain N% at HN followed by Emmer 1. Grain N% of bread wheat cultivars was significantly lesser ($P < 0.001$) than all other genotypes at all N levels. Also, straw N% of bread wheat cultivars was significantly ($P < 0.001$) lesser than ancient wheat species. It was clear that the N% of straw in bread wheat, especially at HN, was lower than other genotypes indicating its ability to remobilise more N towards grain production hence increase grain yield. Grain N% was significantly lower in bread wheat cultivars throughout the study while recording highest grain yield, this phenomenon is commonly identified as the N dilution effect. Grain yield of modern bread wheat was increased significantly during the last few decades. On average, grain yield of spelt, Emmer and Einkorn was 37%, 55% and 62%, respectively, which is lower than the bread wheat (Longin et al., 2016; Geisslitz et al., 2018). This is one of the main challenges faced by wheat breeders; increase grain yield without decreasing grain protein concentration. Einkorn and Emmer genotypes had less grain yield hence more grain N%. Moudry et al. (2011) reported that crude protein yield per hectare of Emmer and Spelt was higher than the bread wheat. Spelt contains more protein (Bonafaccia et al., 2000), fat, vitamins and minerals (Stepień et al., 2016) compared to modern bread wheat. Furthermore, immiunoreactive protein and peptides content was low in tetraploid and diploid wheat such as Emmer and Einkorn compared to hexaploid wheat including spelt and bread wheat (Schalk et al., 2017). Absence of celiac disease active 33-mer peptide is detected in Emmer and Einkorn due to the absence of D genome. However, 33-mer peptide was detected in hexaploid wheat of spelt and bread wheat where D genome is present (Schalk et al., 2017). Christopher et al. (2018) studied on the potential of integration of Emmer flour on health-targeted food design suggested that Emmer wheat with hull could be used to prepare dietary products to support patients of type 2 diabetes.

H. Uptake and Partitioning of N into different plant organs

N treatment ($P < 0.01$) and genotype ($P < 0.001$) were significantly affected on total plant N uptake in 2013, while GT x N was not significant. Spelt Tauro had the highest total plant N uptake at NN and Emmer 2 at HN while Einkorn 2 recorded the lowest value at NN and Einkorn 1 at HN (Figure 3C). When averaged across the species at NN, the highest total plant N uptake was observed in Spelt followed by Emmer, bread wheat and Einkorn while at HN, Emmer took up most N hence total plant N uptake was higher than other species. High total plant N uptake of Emmer may be associated with the plant height, hence AGB production. In addition to that, plant N uptake of Emmer might be influenced by favourable root system characteristics for N uptake (Fernando et al., unpublished data). Feng et al. (2017) discussed the genetic potential of Emmer for improving bread wheat yield, quality and tolerance to drought and salinity. Total plant N uptake differed significantly between genotypes ($P < 0.05$) and N treatment ($P < 0.001$) in 2014. The less variation reported in total plant N uptake among genotypes may be associated with the exclusion of the Einkorn from the experiment in 2014 when compared to 2013. Spelt SB had the most total plant N uptake at NN while Emmer 2 uptake most N at HN. Total plant N uptake was significantly affected by wheat species ($P < 0.05$) and N treatment ($P < 0.001$) where spelt and Emmer had higher total plant N uptake than bread wheat regardless of the N treatment. The total variance of total plant N uptake varied mainly due to N treatment than the genotypic effect for both experiments. Effect of N treatment contributed largely on the total variance on total plant N uptake in 2014 than in 2013. However, the contribution of genotype on the total variance of total plant N uptake was relatively high in 2013 (Figure 4). This may be due to the wide genetic background of the genetic materials used in the experiment. Further, in 2014, Einkorn genotypes were excluded from the experiment hence reduced the genotypic diversity.

In general, about 17% of total plant N was in straw for all genotypes and this value increased with N supplies ($P < 0.05$) in 2013. However, in 2014, genotype ($P < 0.001$) differed in their proportion of total plant N in straw and there was a significant interaction between GT x N ($P < 0.01$). N supply had a positive relationship with the proportion of the N in straw (19.78%). Therefore, it can be said that the increased supply of N fertiliser may increase residual N in straw as structural N at harvest. This helps indirectly to reduce N accumulation in the surface water bodies and groundwater table due to N fertiliser losses to the environment.

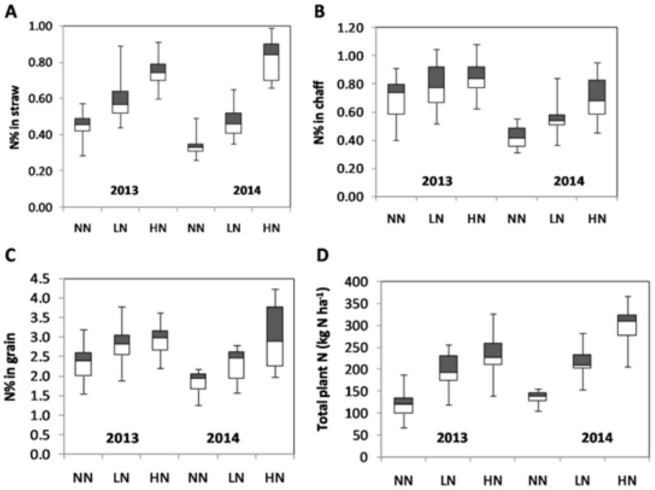

Fig. 3. Distribution of means of (A) straw N% (B) chaff N% (C) grain N% (D) total plant N uptake (kgN ha^{-1}) among the replicates in 2013 and 2014 field experiments

In both experiments, the contribution of total plant N to chaff N at maturity was significantly affected by genotype ($P < 0.001$) and GT x N ($P < 0.01$) where 8.5% and 13.5% of the plant N was in chaff in 2013 and 2014, respectively. In 2013, there was no effect of main factors and the interaction for the proportion of the plant N in grains. However, genotype ($P < 0.05$), N treatment ($P < 0.01$) and GT x N ($P < 0.01$) were significant in 2014. About 74% and 67% of plant N was found in grains in 2013 and 2014 experiments, respectively (Figure 5A and B).

Effect of species on residual N in straw was significant for both experiments ($P < 0.05$) where N treatment and species x N interaction was only significant in 2014 ($P < 0.001$). However, the proportion of plant N in chaff and grain were not affected by species in 2013 but significant in 2014 ($P < 0.001$ for chaff and $P < 0.01$ for grain). Nevertheless, N treatment was significant for N in chaff and grain in 2013 ($P < 0.001$ and $P < 0.05$) while only significant for grain N in 2014 ($P < 0.01$). In 2013 and 2014 experiment, in general, grain N content as a proportion to total plant N was 74% and 67%, respectively. According to Vaidyanathan (1984) grain

TABLE III

ANOVA TABLE OF THE EFFECT OF N FERTILISER AND GENOTYPE ON N% IN STRAW, CHAFF AND GRAIN TOGETHER WITH TOTAL PLANT N UPTAKE (KGN HA^{-1}) IN 2013 EXPERIMENT

Source of variation	df	Mean Square			
		Straw N%	Chaff N%	Grain N%	Total plant N uptake (kgN ha^{-1})
Whole plot					
N level (N)	2	0.490***	0.150**	2.620***	84043**
Whole plot error	4	0.003	0.007	0.020	2164
Subplot					
Genotype (GT))	7	0.026***	0.110***	1.890***	4246***
N x GT	14	0.020***	0.020***	0.098***	828^{NS}
Subplot error	42	0.002	0.004	0.009	1022

***significant at = 0.001
**significant at = 0.01 NS = not significant

TABLE IV

ANOVA TABLE OF THE EFFECT OF N FERTILISER AND GENOTYPE ON N% IN STRAW, CHAFF AND GRAIN TOGETHER WITH TOTAL PLANT N UPTAKE (KGN HA^{-1}) IN 2014 EXPERIMENT

Source of variation	df	Mean Square			
		Straw N%	Chaff N%	Grain N%	Total plant N uptake (kgN ha^{-1})
Whole plot					
N level (N)	2	1.303***	0.402**	6.955***	137568**
Whole plot error	4	0.001	0.003	0.027	279.1
Subplot					
Genotype (GT))	6	0.006***	0.045***	1.809***	2066.3***
N x GT	12	0.021***	0.038***	0.401***	1015.2^{NS}
Subplot error	36	0.002	0.002	0.006	762.9

***significant at = 0.001.
**significant at = 0.01. NS = not significant.

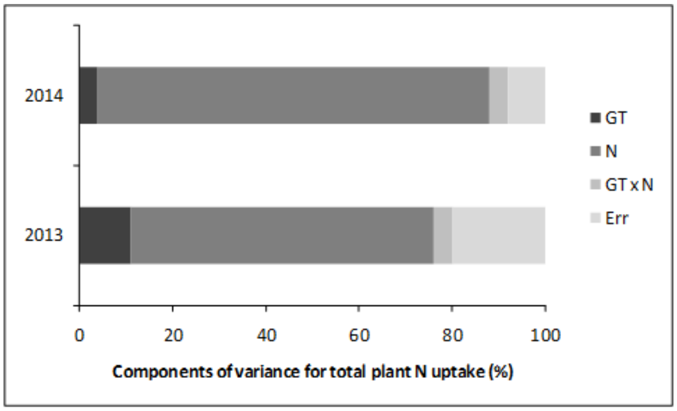

Fig. 4. Contribution of components of variance on total variance of Total plant N uptake at maturity in 2013 and 2014 experiments (GT; genotype, N; N fertiliser, GT x N; genotype by N level interaction and Err; error)

N represents approximately 75% of total plant N for cereals. Further, 18 to 19% of total plant N was observed in straw and 9 to 13% in the chaff. Lodging encountered in Emmer and Einkorn might have a negative influence on N remobilisation to grains in both experiments. However, sever lodging in ancient wheat species was not reported in the present study. A small amount of N expected to be in the root systems (10- 20%; Anderson Johansson, 2006) though, it was not accounted for in this study.

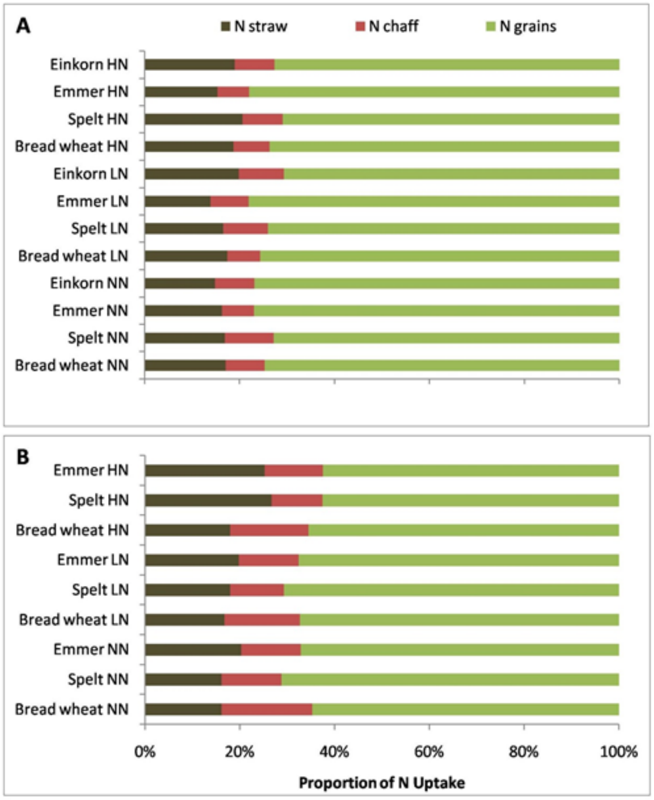

Fig. 5. Proportion of total plant N in straw, chaff, and grain at maturity in (A) 2013 and (B) 2014 experiments

Partitioning of total plant N to straw, chaff and grain N gradually increased with N supply. The previous study reported a positive response of all straw components toward N uptake partitioning at high N level (Cox et al., 1985). Genotypic differences in N partitioning at maturity in both experiments were significant. This may be due to the vast genetic background of the genotypes used in the study which belong to four species of wheat. Pask (2009) suggested that the possible reason for the varietal difference in N partitioning for the straw at harvest may be associated with true stem length.

IV. CONCLUSION

Ancient wheat species may have the ability to uptake more nitrogen and store in plant structures than modern bread wheat. This may be associated with the plant height of the ancient wheat species. Grain N% of all wheat species is greater than the N% in straw and chaff. There could be a negative relationship between high N% in grains and grain yield and a positive relationship with grain protein content in ancient wheat. High plant N uptake of ancient wheat species and trapped N in the straw indirectly reduce fertiliser N losses to the environment.

AUTHOR CONTRIBUTION

KMC Fernando- Design and conduct the field experiments, collection, analysis and interpretation of data, writing the manuscript; DL Sparkes- provide guidance to design and conduct the field experiments.

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